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INTEGRATED FLIGHT TRAJECTORY CONTROL DEVELOPMENT PROGRAM

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Previous IFTC programs have demonstrated by simulation the ability to compute four-dimensional reference trajectories and provide guidance commands to the pitch and roll autopilot axes for vertical and lateral aircraft control, and to the autothrottle for thrust and accurate time-of-arrival control.

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19. (Continued)

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Data-link	Maneuvering weapon-
Interactive controls–displays	delivery
Data transfer system	Projected map

20. (Continued)

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The IFTC Development Program has been concerned with adding certain functions to increase the tactical flight management capabilities of the concept. IFTC was integrated with the Firefly II advanced air-to-ground weapon delivery algorithms to provide ingress and egress flight path generation and control. The LSI-developed Mission Data Transfer System (MDTS) was added to the simulation to demonstrate the aid to mission planning and the rapid data initialization of the simulated airborne system.

The CRT used for the Tactical Map Display was replaced by an Electronic Projected Map Display (EPMD), which allowed the combined display on one surface of the Tactical Planning Chart (TPC) image and the graphics generated image of the flight plan, including the aircraft image, hostile and friendly bogies, and ground threat envelopes.

Pilot testing and evaluation of the concept was performed using the LSI man-in-the-loop cockpit simulator.

SUMMARY

Previous IFTC programs have demonstrated by simulation the ability to compute four-dimensional reference trajectories and provide guidance commands to the pitch and roll autopilot axes for vertical and lateral aircraft control, and to the autothrottle for thrust and accurate time-of-arrival control.

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Pilot testing and evaluation of the concept was performed using the LSI man-in-the-loop cockpit simulator.

Four pilot test subjects were used to evaluate the IFTC concept, the installation and use of the EPMD and MDTS with IFTC, and the IFTC/Firefly II weapon delivery integration. The post-flight questionnaire was structured to elicit responses with respect to these four areas. Copies of the blank questionnaires are included as Appendix B, and a complete discussion of the results appears in Section 6.5.

For the reader's benefit, those results are summarized in this section. The summary is presented in four sections: IFTC time-of-arrival/time-on-target control (TOA/TOT); Mission Data Transfer System (MDTS); Electronic Projected Map Display (EPMD); and IFTC/Firefly II weapon delivery integration.

IFTC-TOA/TOT

All pilots agreed that TOA/TOT control is very important -- extremely important for certain missions such as nuclear delivery and multiple

strike. Because IFTC performs several functions that are presently
performed manually, it was felt that pilot workload should certainly be
reduced. Because of the increased tactical situation awareness and
response and display capabilities afforded by IFTC, survivability
should also be increased. It was also believed that the automatic
trajectory and time/speed schedule adjustments following mission inter-
ruptions would greatly increase the operational capability.

The autothrottle, operating with the commands generated by the speed/
time guidance functions, was considered to be a strong asset.

MDTS

Current nav planning techniques consume from 70% to 90% of the total
mission planning time; this is a disproportionate amount which does not
allow as much time as pilots would like for tactics planning. It was
their feeling that the Mission Data Transfer System (MDTS) system would
increase the tactics planning time by considerably decreasing the nav
planning time.

The feeling was unanimous, however, that to be fully effective, or even
acceptable, the MDTS must provide the necessary nav planning parameters
of flight leg distance, time-of-arrival estimates, and fuel use esti-
mates. These are quantities that could easily be computed by modifying
the MDTS software to include the T.O. 1F-XX-1 Flight Manual data for
all aircraft and models being served by that particular MDTS installa-
tion.

It was also suggested by the pilots that the output be printed in a
format consistent with the standard AF FORM 70, the format with which
all pilots are familiar. Input of nav point position data could be ex-
pedited by use of a hand-held digitizer with the Tactical Planning
Chart (TPC) either attached to or projected on the digitizer board.

All the pilots felt that something similar to the MDTS, but with the
additions just noted, would be required to expediently handle the data
requirements of an IFTC-like system. To expect the pilot to use a
cockpit key pad to enter the quantity of data required would be unac-
ceptable.

EPMD

All the test subjects were enthusiastic about the electronic, projected
map. Use of present cockpit maps (A-7D, F-111D) emphasizes nav system
and ground track accuracy monitoring. The inclusion of electronically
generated imagery adds a new dimension to the map use. It provides a
way of displaying the flight plan (and alternates) including the true
turn radii, displaying ground threat footprints, hostile and enemy air
threats, and capture profile paths following deviations. It also pro-
vides a means for annotation of the map with special symbols and for
the display of selected alphanumeric information.

IFTC/Firefly II Weapon Delivery Integration

The concept of offset bombing while pulling g's seemed viable to the pilots. It provides a natural avoidance of fragmentation, and increases tracking difficulty for the ground defenses.

It was judged to be very useful to allow the pilot to specify the weapon delivery parameters of target penetration distance, delivery and egress g's, the attack initiation altitude and angle-off, and to have the IFTC algorithm automatically compute the position of the attack initiation point (AIP) as a function of the specified values.

IFTC guidance provided pitch and roll steering commands to the HUD flight director and to the autopilot for either manual or automatic steering to the AIP. The pilots preferred fully coupled steering during ingress, as long as immediate, manual override was possible. Re-adjustment of the AIP position as a result of jinking or other ingress maneuvers was judged necessary. The pilots had full flexibility to adjust the attack profile heading by simply flying the aircraft to a new position with respect to the target. IFTC automatically re-positioned the AIP position as the A/C position changed.

After sufficient training to understand the delivery and egress control philosophy of manual g-loading of the aircraft and automatic roll angle control, the pilots were receptive to the concept of semi-inverted flight during egress for the purpose of rapidly returning to low-level, stable flight. It was suggested that if release occurs at an altitude below 1000 feet, the egress roll angle be limited to 90 degrees, otherwise 120 degrees was quite acceptable.

The following seven sections describe the program in more detail. Section 2 describes the IFTC concept, and approaches the subject by first providing a system description, followed by a discussion of anticipated operational capabilities. Section 3 describes the EPMD from a hardware perspective.

Section 4 examines the MDTS, first from a hardware point-of-view, looking at the data transfer module, the cockpit receptacle for the module, and the ground-based hardware. Finally, the mission planning procedures are examined. Section 5 discusses the IFTC/Firefly II weapon delivery integration. Each phase of the delivery, ingress, delivery, egress, and re-attack is discussed separately.

Section 6 describes the pilot testing - the purpose, the method of testing, the testing scenario, and the results.

Section 7 gives a brief description of the man-in-the-loop simulation. Section 8 provides some recommendations for future work, with a discussion of adding fuel management capability to IFTC and replacing the EPMD with a completely digital-based color map. Also discussed is the

possibility of adding the ground threat/terrain footprint results from the Purple Haze[12] program to the digital map display, as well as using trajectory optimization techniques for determining minimum exposure profiles through or around the threat footprints.

Also included is a discussion recommending that further work be performed to apply the IFTC/Firefly II weapon delivery technology to provide time-spatial coordination of a multiple aircraft attack.

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1 INTRODUCTION AND PROGRAM DESCRIPTION

1.1 INTRODUCTION

The proliferation of increasingly sophisticated enemy military forces in the past decade, and the ability to apply those forces quickly and anywhere in the world has stressed the importance of a demonstrated deterrent capability. This capability must combine rapid reaction with the ability to apply the appropriate force at the appropriate place. Strategic and tactical power, global mobility, and a precise, well-ordered strike capability are necessary parts of the required capability.

The next major confrontation will likely be intense, tactical, and non-nuclear, at least during the initial phases. The battle area will be defended heavily by defensive weapons (SAMs, AAA) and enemy fighter aircraft. The number of enemy fighters will probably exceed the number of friendly aircraft. The friendly pilot will be concerned with enemy aircraft and ground defenses. Therefore, by giving the pilot an accurate, current knowledge of his tactical situation, his probabilities of survival and mission success are increased.

Communication and accurate time-space coordination will also be required capabilities in the next conflict. The ability to strike both at night and in adverse weather, and to successfully redirect to targets of a higher priority -- all in a timely and well-coordinated fashion -- will help to offset the superiority of enemy aircraft numbers.

The increase in more sophisticated weapons, on-board sensors and aircraft and control freedom will be accompanied by increases in pilot workload. Unless the control tasks are automated and simplified to reduce the pilot's workload, the cockpit workload will become unmanageable.

The Integrated Flight Trajectory Control (IFTC) program has been concerned with solving these problems. The solution is not simply one of a better design of the cockpit controls and displays to reduce the number of button pushings and switch selections. It must involve the development of a system which adds flight management capabilities through the use of digital computers to integrate guidance and control with control and display, navigation, weapon delivery, data link systems, rapid data transfer devices, and other on-board sensors.

The IFTC program objective is to expand the flight management capabilities of on-board equipment to reduce the pilot workload required to operate in a hostile tactical environment, including real-time mission redirects provided by data links or pilot initiative.

The projected tactical scenario characterized by superior numbers of enemy air and ground offensive and defensive systems will require the friendly forces to maintain tactical air superiority through efficient use of their aircraft; in other words, through the use of force multipliers. Friendly forces will fly missions into enemy territory under night and adverse weather conditions to neutralize enemy ground movements. Because of the fluid nature of the battle area, command and control (C^2) will be heavily utilized for directing and redirecting airborne forces. Jam-resistant digital communication links will supply C^2 directives and up-to-date ground and airborne threat information, and precision navigation information for night and adverse weather operation will be required.

Many of the mission types will be characterized by complex profiles with one or more time-critical points such as time-on-target (TOT), time at the FEBA (forward edge of battle area) for IFF (identification friend or foe), and time-of-arrival at the refueling tanker. Specific types of missions which would be enhanced by precision time-space coordination are:

- Air assault missions requiring timely support from air defense, stand-off jammers, and gunships for mission success and survivability.

- Interdiction missions requiring time-scheduling of the suppression of enemy defenses.

- Airlift missions requiring timely air and ground defense support during time intervals of high vulnerability to enemy attack.

- Night and adverse weather missions flown in conditions of high cockpit workload.

The possibility of a redirect occurring during any of these mission types is high. The real-time redirection capability and the increased availability of tactical data provided by the data-link network should serve as a force multiplier for the friendly forces. This capability, however, will undoubtedly increase the cockpit workload. Targets will change, refuelings will be rescheduled, ingress/egress routes will vary, and deviations will occur because of hostile bogies, SAM, and AAA threats.

With existing cockpit capabilities and a redirect based on the data link position messages, the new mission routes would be plotted on the navigation maps. Aircraft performance charts would be used to determine fuel usage based on rough cut time-of-arrival and airspeed calculations. Rendezvous for refuel and bingo fuel points would be considered. Survivability would be a prime consideration. The total threat situation would be assessed with respect to the new mission profile.

If the redirected mission is of sufficient priority to warrant the risks, the pilot must indicate to his controller the decision to comply and enter the appropriate data into his navigation equipment. If the pilot determines that he cannot comply, the entire process repeats, and a prime target may escape destruction.

These plan variations can and will occur after takeoff, and the pilot's ability to respond favorably to each will be determined by the flexibility of the cockpit controls, displays, and sensors.

Existing cockpit equipment (autopilots, flight directors, and inertial navigation systems) provide pilot relief and steering cues for flying under essentially constant conditions of attitude, heading, altitude and speed, or for flying straight line segments between stored mission destination points. This equipment, with navigation maps and hand calculations, is used to navigate the mission route and meet any specified target and rendezvous times. Fuel-remaining estimates at mission and refuel points are computed during the mission planning exercise. Deviations from this original mission plan, caused by the need to avoid the lethal airspace around a new enemy SAM location, by the need to divert from the current course because of the proximity of hostile bogies, or by profile changes to take advantage of terrain features for radar masking, will require the pilot to work with the navigation maps to determine the best return path to the original mission profile. These disruptions, of course, will force revisions of the profile, the time schedule, and the fuel use estimates.

This level of cockpit workload is formidable under non-combat circumstances, and nearly impossible under the stress associated with combat situations. Furthermore, planning for mission changes and redirects reduces the time available for operation of radar,

communication receivers, navigation equipment, and jamming equipment. Heads-up "window time", necessary for early visual detection of enemy aircraft, a major concern and activity, is also greatly reduced.

To help solve these problems, IFTC provides automatic, real-time trajectory generation in response to deviations from the nominal flight plan, as might occur as a result of ground or air threat avoidance, or in response to a complete flight plan change, as might occur as a result of a data-link redirect. In the first situation, IFTC computes a transition trajectory from the aircraft position to the next point in the mission plan. In the second situation, a totally new flight profile is computed through the redirect mission points and a transition trajectory links the aircraft to the first point in the new mission.

All trajectories consist of curvilinear segments, which account for the expected aircraft speed and bank angle during turns. Estimates of arrival times and fuel reserves are computed for each point in the mission and are available for display to the pilot.

To further reduce cockpit workload, the pilot may choose to have the IFTC guidance function control the aircraft by providing pitch and roll steering signals to the autopilot. The steering signals are generated as a function of the tracking errors with respect to the nominal profile.

If a desired time-of-arrival (TOA) is specified at a critical mission point, a speed-time schedule is generated and the throttle is controlled to maintain an accurate TOA. Throttle control exists either through an autothrottle system or a flight director cue to the pilot.

Any deviation from the reference profile results in a recomputation of the speed-time schedule. The aircraft speed is adjusted to maintain the TOA.

Cathode ray tubes (CRTs) are used for displaying pictorially the mission profile, ground and air threats, alphanumerics, and other information important to the pilot's awareness of the tactical situation.

To restate the concern of the IFTC program: Given a dense threat environment, a fluid battle situation, the availability of large amounts of tactical information, in a redirect posture the increased pilot workload will in all likelihood make the pilot the limiting factor in the execution of time-critical and redirected missions. Consequently, the operational improvements provided by C^2 and other advanced tactical systems may not be achieveable because of the inability of the pilot to assimilate the tactical situation information, digest it, and take appropriate cockpit and aircraft control actions.

The following pages summarize the work performed by the Instrument Division of Lear Siegler, Grand Rapids, Michigan, on the Integrated Flight Trajectory Control (IFTC) Program Development contract, under sponsorship of the Air Force Flight Dynamics Laboratory, Flight Controls Division, Wright-Patterson Air Force Base, Ohio.

1.2 IFTC HISTORY

The IFTC technology has been developed on two previous programs: Feasibility Study for Integrated Flight Trajectory Control (Airlift)[1] and Feasibility Study for Integrated Flight Trajectory Control (Fighter)[2]. Both programs were performed by LSI under contract to the Air Force Flight Dynamics Laboratory.

The airlift program applied the concept of automatic, on-board, four-dimensional trajectory generation and automatic guidance and control along the trajectory to the terminal area control requirements of military transports. Reference [5] also describes the efforts of that program.

The major emphasis of the fighter program was to apply the concepts and techniques of trajectory generation and guidance to the fighter aircraft mission tasks. These tasks included air-to-ground weapon delivery, rendezvous for refueling, and time coordinated strike missions. The trajectory generation, guidance, and control/display algorithms were refined to satisfy the unique fighter aircraft requirements. In addition, tle response of the trajectory generator (including the time-speed aspects) to advanced data link inputs was investigated. The data link inputs included hostile and friendly aircraft positions and updates, SAM threats, and mission redirects.

The transport program identified the need for a vertical situation mode for the map display. One possible format for this mode was defined and implemented for the fighter program. A simplified algorithm for automatic ground threat avoidance was also implemented and demonstrated.

Both airlift and fighter program algorithms were programmed and installed in the LSI Hybrid Simulation Computing Facility and were used for performing real-time pilot-in-the-loop testing. The final reports for both programs, [1] and [2], summarize the results of the pilot testing.

The fighter program was described in an Air Force 16-mm sound and color movie[6], and was also the subject of a NATO AGARD Guidance and Control Panel Symposium paper[7] as well as an article in Aviation Week and Space Technology[8].

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IFTC was involved in another program paralleling the Development Program. This program, known as the Operational Applications Analysis - F-15/Integrated Flight Trajectory Control, (F-15/OAA)[10], was also under the sponsorship of the Air Force Flight Dynamics Laboratory which awarded the study contract to McDonnell Douglas Corp. in July 1979. LSI was under subcontract to McDonnell Douglas, in a teaming arrangement which evaluated the application of the IFTC concepts to a current operational fighter in a realistic scenario using the McDonnell Douglas F-15 as a typical modern fighter aircraft. F-15 operational missions were reviewed and mission segments were identified for which IFTC would be beneficial in terms of mission performance and survivability. Changes and additions to the IFTC algorithms were identified to enable compatibility with the F-15.

An IFTC control/display implementation for the F-15/OAA was designed to function in concert with the advanced F-15 and Joint Tactical Information Distribution System (JTIDS) control and display concepts. Estimates of the airborne computer capacity required to add the IFTC algorithms to the existing F-15 computer indicated that expansion of the computer to its maximum design value would allow sufficient memory and execution time to accommodate the IFTC algorithms.

1.3 IFTC DEVELOPMENT PROGRAM DESCRIPTION

1.3.1 Electronic Projected Map Display (EPMD)

To use the IFTC concepts as the foundation for a tactical flight management system, it was felt that further development was required in at least three areas. Both the airlift and fighter study programs utilized cathode ray tube (CRT) displays for the tactical map information. This information included the primary mission profile and one or more secondary profiles, hostile and friendly air element locations, ground-based SAMs and AAAs, and data-link redirect missions. Also displayed were several alphanumeric data windows. While this approach was quite adequate for displaying the electronically generated information, it still required the pilot to use hand-held tactical planning maps for referencing the electronic information to the world below. This becomes particularly cumbersome and time-consuming when the pilot is given a redirect which, in most cases, would require him to traverse geography unfamiliar to him.

One solution to this problem was to utilize a cockpit display which has the capability of displaying both the electronically generated data and profiles and some representation of the features found on the tactical planning maps. By combining both sets of information on one display, the pilot is able to make full use of each, with a minimum of head movement and mental integration of

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the two classes of information, as would be required for a multiple display approach. One device available with the capability of displaying both classes of information is the Electronic Projected Map Display (EPMD) manufactured by Ferranti, Ltd. of Scotland, U.K. This display uses a 35-mm film format for the tactical map information and a CRT and projection system for displaying the graphics information in a conventional raster format. An optics system is used to combine the information from both sources. The EPMD display, shown in Figure 1, is described in Section 3.

1.3.2 Mission Data Transfer Unit (MDTS)

Because flight management systems process large amounts of data, much of which is related to primary and secondary mission definition and navigation sensor initialization, it becomes necessary to load the flight management computer with equally large amounts of data. Using keyboards for manual, in-the-cockpit loading of this data by the pilot is undesirable because it adds to both the pilot's fatigue and the mission reaction time, and the process is very subject to error. In short, most pilots dislike keyboards for any kind of extensive data entry or modification.
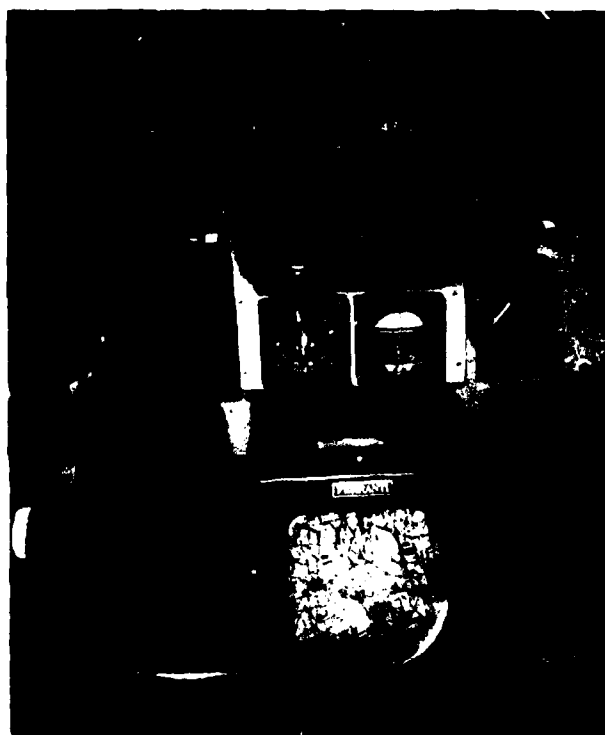
Figure 1. Electronic Projected Map Display

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One solution to this problem is to use a bulk memory storage device which could be loaded with the necessary data by a ground support computer in or near the mission planning room. This device could be used to store data defining prime and several alternate flight plans, known ground-based threats, and sensor initialization parameters such as those required by the inertial nav system, Loran or Global Positioning System, and IFF codes, to name a few. To be useful, this device would need to be shirt-pocket-sized, easy to load in the briefing room, swift to transfer its contents to the flight computer, and would not require delicate handling to ensure reliability.

Such a system, the Mission Data Transfer System (MDTS), was available, having been developed and produced by LSI for the USAF ARN-101 system. The Data Transfer System is used on the F-4E and RF-4C aircraft. The system equipment consists of a ground-based computer, two user terminals, disc data storage device, paper tape reader, printer and load receptacle. The aircraft contains a companion receptacle to receive the module for loading the airborne computer. The system is shown in Figure 2 and the module in Figure 3. The data module contains a battery-maintained, solid-state memory, eliminating the slow speed and reliability problems associated with magnetic tape-based systems.

Because of Air Force interest, it was decided to install the Data Transfer System in the simulator lab and make the necessary modifications to the IFTC software to allow loading the data transfer module (DTM) data into the simulation computer, from the cockpit. This addition to the IFTC Development Program allowed the pilot test subjects to use the Data Transfer System in the mission planning phase to construct their primary mission and load this information as well as known SAM and AAA locations into the memory module. The module was then carried to the cockpit and loaded into the simulation computer. This capability gave each pilot a "hands-on" demonstration of the field use of the system. The Data Transfer System is described in detail in Section 4.

1.3.3 Weapon Delivery

Because of the Flight Dynamics Laboratory's involvement with advanced air-to-air and air-to-ground weapon delivery techniques, it was determined that the IFTC Development Program would provide a good opportunity for demonstrating the integration of an on-board trajectory, time and guidance control system with advanced air-to-ground bombing. Specifically, the Firefly II air-to-ground algorithms were implemented in the IFTC computer and the IFTC trajectory and control algorithms were modified to allow pitch and roll control of the aircraft to a computed point, offset with respect to the target. The position of the offset point is computed based on certain pilot-specified parameters for the delivery. These
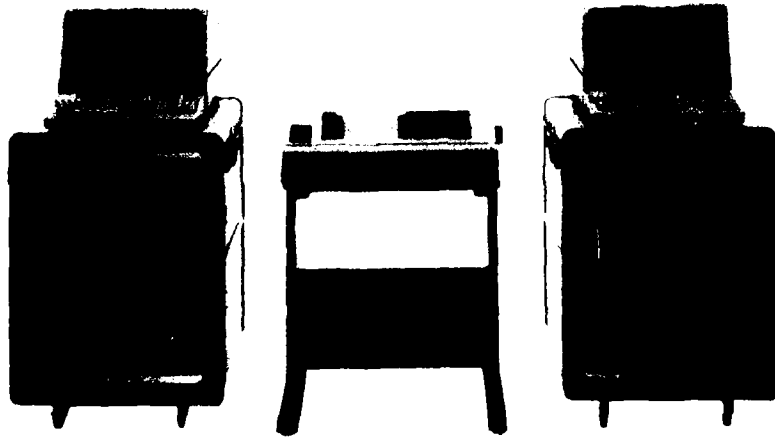
Figure 2.   Mission Data Transfer System
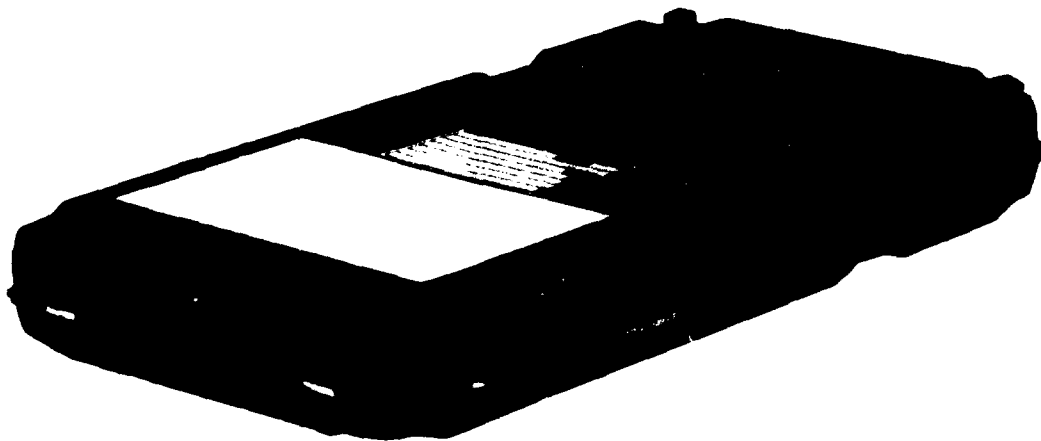
Figure 3.   Data Transfer Module

parameters include delivery and egress 'g' loading, minimum penetration distance to the target, entry point altitude, and the angle-off value.

A typical air-to-ground, low-level bombing mission using the IFTC/Firefly II integration is shown in Figure 4, and is described in Section 5.

1.3.4   Pilot Testing

After installation of the EPMD map and the Data Transfer System, and the implementation IFTC/Firefly II weapon delivery, the simulation was debugged and declared ready for pilot testing. A high-resolution black and white monitor was installed in the cockpit as a HUD simulator. The EPMD display was installed in place of the CRT tactical situation display used for the previous program. The control/display procedures for pilot/system interaction were left intact from the previous design, and the same F-4 aircraft model was used. The guidance commands were coupled to a fly-by-wire flight control system developed for the F-4 as described in Reference [9].

Some modifications were made to this flight control system to accommodate the special requirements of IFTC/Firefly II.

Pilot training and testing began in January, 1981 with a total of four pilots participating. Pre-flight and post-flight questionnaires were used to sample the pilots' reactions to the system. These results are summarized in Section 6. The questionnaires are included in Appendix B.
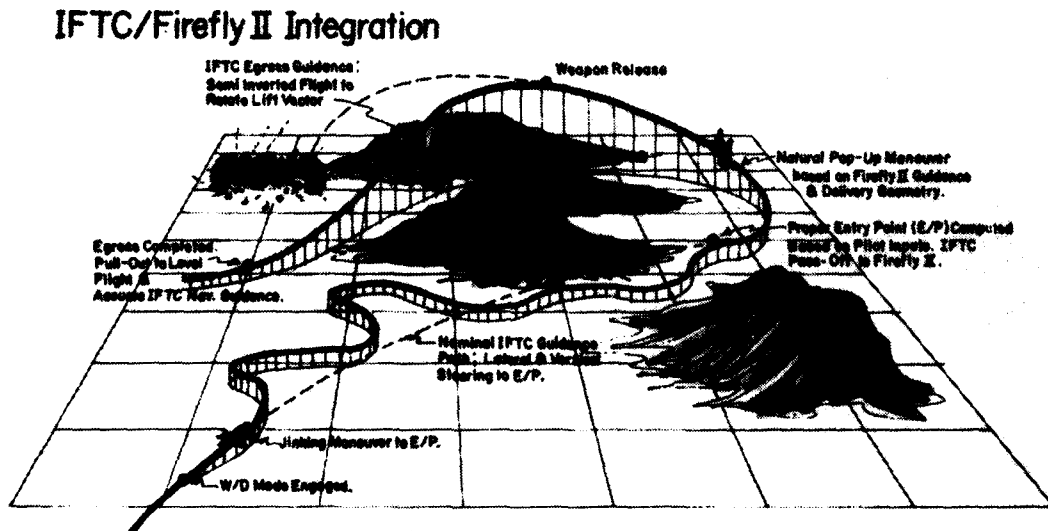
Figure 4.   Integrated IFTC/Firefly II Weapon Delivery

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2 THE INTEGRATED FLIGHT TRAJECTORY CONTROL CONCEPT

2.1 SYSTEM DESCRIPTION

The Integrated Flight Trajectory Control program has developed a flight management system concept that will provide pilots with increased capabilities during the execution of tactical missions. The key functions forming the foundation of the system are:

- Real-time computation of four-dimensional trajectories (X, Y, Z, and time)

- Automatic pitch, roll, and throttle control of the aircraft along the trajectory

- Automatic response to command and control data-link inputs

- Integration of the cockpit control and display functions with the flight management functions

- Integration of IFTC and Firefly II advanced weapon delivery concepts

- Integration of the Mission Data Transfer System (MDTS) with IFTC for improved mission planning and rapid transfer of mission data to the flight management computer

- Installation and integration of the electronic projected map (EPMD) as the tactical situation display (TSD)

Figure 5 illustrates the integration of these functions with the navigation and communication as well as with the cockpit displays, controls, data transfer device, and the aircraft flight controls. Digital processing is used to achieve the integration. In particular, the computer processes:

a. Aircraft position, velocity, and altitude inputs from the aircraft navigation system

b. Tactical situation and command/control data from the data-link network

c. Pilot inputs expressed through the interactive control/display hardware

d. Flight plan and intelligence data as well as sensor initialization data from the data transfer module (DTM)

e. Map positioning commands for the EPMD

IFTC PROCESSING

- 3-D TRAJECTORY
- SPEED / TIME SCHED.
- ADVANCED W/D
- GUIDANCE CONTROL
- COMMAND CONTROL
- CONTROL / DISPLAY

NAVIGATION SENSORS

COMMUNICAT'N SYSTEMS

BULK DATA STORAGE

AIRCRAFT STATE

AIRCRAFT CONTROLS & CONTROL SYSTEM

INTEGRATED COCKPIT DISPLAYS
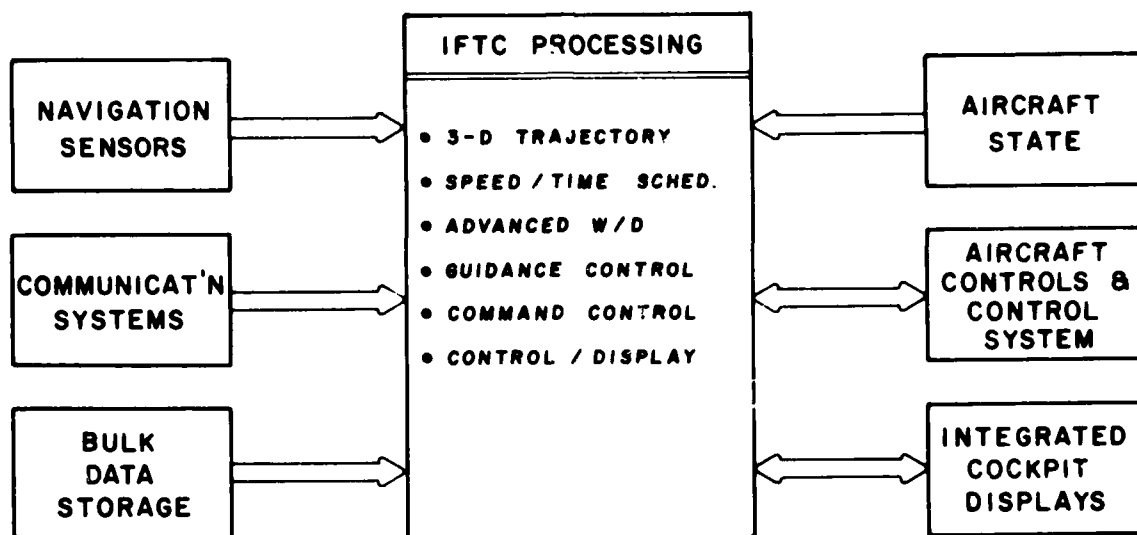
Figure 5.   IFTC System Block Diagram

f.   Graphics symbology for the EPMD TSD

g.   Weapon delivery geometry, ballistics, and guidance commands

h.   Aircraft guidance and control commands

The trajectory generator computes the four-dimensional trajectory based on data defining the mission profile and known threat environments.   The mission profile data consists of a sequence of points used to define the mission and any alternates.   These points may be waypoints, targets, target initial points, refuel rendezvous points, and approach points defined by -- at the least -- X, Y, and Z coordinates.   For critical mission points the pilot may also specify times-of-arrival (TOA) and speed.   TOA's and desired speed are used as hard constraints by the trajectory generator to compute the speed and time profile.

After computation of the parameters completely defining the horizontal, vertical, and speed/time profile, the fuel use estimates and estimated times-of-arrival for each profile segment are computed.   Operational limitations, control law authority, and predicted winds serve as constraints on the computed trajectory.   The guidance and control functions provide tracking of the nominal profile and maintain the speed and time schedule.

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Either automatic or manual modes of control are selectable, with independent selection between the pitch and roll channels and the throttle channel. The automatic mode relieves the pilot of performing the tracking tasks. Full manual control may be quickly assumed by the pilot, however, for rapid, unplanned mission activities such as jinking and bogie avoidance.

Pitch, roll, and throttle position commands are provided by the flight control laws and displayed on the attitude director indicator during manual mode operation. Pitch and roll flight directors are available on the HUD during weapon delivery.

The ease and confidence with which the pilot is able to use any advanced cockpit system determines the usefulness of the system. The pilot will consider the system useful if it reduces his workload in accomplishing his normal tasks, or if it allows him greater capability for completing a mission that would normally be aborted because of increased workload. The goal of the control/display design was to minimize the number of pilot actions required to communicate with the IFTC system. Electronic displays, dedicated and multifunction keyboards, a hand-controlled crosshair designator, and a computer for automation have been used to accomplish this goal.

The Tactical Situation Display is used for displaying tactical data including the engaged flight profile, known and detected SAM and AAA envelopes, hostile and friendly aircraft locations, current aircraft position and track, and alternate flight plans. In addition to these classes of information which are displayed in symbolic form, aircraft track angle, map scale, ground speed, engaged plan number, assigned time-of-arrival and time-of-arrival error are displayed in alphanumeric format. The corresponding frame from the Tactical Planning Chart (TPC) is projected for the pilot's use, and in the scale selected.

A second electronic display, the Status Display, is used for presenting alphanumeric information. The data is arranged in page format and the keyboard associated with this display is used for making data deletions, additions, or corrections.

Data link information is processed automatically by the computer and presented on the displays. This processing may be as simple as presenting symbols of hostile or friendly aircraft, direction of flight, and altitude (if known) on the EPMD. It may be as complex as processing the data associated with a command and control (C^2) mission redirect, for which the trajectory generation capabilities are used for computing a direct, flyable profile from the current aircraft position to the first point in the redirect mission and all points thereafter. If time-of-arrival is assigned at one or more points in the redirect mission, the time-speed portions of the trajectory generator use these assigned values as

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hard constraints and attempt to construct a speed-time schedule, within its control authority limits, to satisfy the times-of-arrival. If the arrival times cannot be satisfied, the pilot is notified immediately via the displays.

2.2 OPERATIONAL CAPABILITIES

The majority of the peacetime missions are flown in controlled airspace with a mix of civil and military aircraft. These missions are flown on well-defined, preplanned routes. Current cockpit equipment has sufficient capability to satisfy the demands of these missions. In times of conflict, however, when well-planned missions become chaotic as a result of prolific enemy ground forces (AAA, SAMs, ZSU-23s) and aircraft, more capability is required.

The IFTC system has been designed with this volatile environment in mind. The trajectory generator accepts new points from the data link (C^2) and computes a new, flyable trajectory after considering aircraft performance parameters, threats, and mission constraints. The Tactical Situation Display (TSD) is used to display the trajectory. Any newly computed trajectories are displayed in dashed format to distinguish them from the engaged profile. This presentation was selected to aid the pilot in recognizing that he has been directed to another target.

The alternate profile includes a speed and time schedule for each flight segment as well as estimates of the fuel remaining at each profile waypoint. These computations would normally be estimated by the pilot if time and cockpit activity permitted, but at the expense of increasing his workload. The automatic computation greatly relieves the pilot workload, and the availability of the data through the cockpit displays and the presentation of the new profile on the TSD allows the pilot to assess the situation quickly and to make the final decision to comply or not comply with the mission redirect request.

The redirect profile could also be initiated by the pilot using the cockpit keyboard and/or the crosshair controller to define a set of points for a new profile.

The capability for acceptance of the data-linked information for display and automatic processing by the trajectory generator demonstrates the potential for a significantly greater amount of pertinent tactical information to be received and evaluated. This automation is accomplished while preserving the philosophy of allowing the pilot to review the incoming data and be the final decision-maker. Without this capability, the requirements for the manual insertion of incoming data would exceed the pilot's capacity.

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The parameters that can be specified for each point of the trajectory are not limited to latitude, longitude, altitude, and time, but may include heading at flyover, flight path angle, turn radius, and speed. The specified parameters are used as constraints by the trajectory generator. The advantages of this capability are especially evident for weapon delivery missions under low visibility conditions in which the aircraft's heading, flight path angle, and speed must be controlled along the desired delivery path. Without the trajectory generator and the automatic control system, significant workload is placed on the pilot to perform the navigation and control functions.

The battle zones of the next conflict will be highly saturated with SAM and AAA emplacements. Present methods dictate that the mission's preplanned route avoid known emplacements. The pilot must perform defensive maneuvers when warned by the onboard equipment. It is at these times that the pilot begins to lose track of his position in relation to the target and especially of his time schedule. With the increased capabilities afforded by the IFTC system, the pilot will continue to have control of his aircraft to perform necessary defensive and/or offensive maneuvers. In addition, he will have a constant display of the best intercept back to the original path or a new, more direct path. This continuous, precise updating of the aircraft parameters, such as position, speed, time on target, and fuel remaining, which can be transmitted to C^2 via the secure data link, will significantly aid the C^2 capability to utilize the strike forces to their greatest advantage. Knowing the fuel situation of each aircraft is beneficial in the prioritizing of the refueling operation and redirect assignments without a high level of voice communication. A few of the flight management capabilities provided by the IFTC system include:

- Accurate time coordinated rendezvous for,

    Refueling operations
    Fighter escort
    Combined strike operations
    Close air support
    Electronic countermeasures protection

- Time-on-target coordination

- Air- and ground-based threat avoidance

- Accurate fuel estimations at future nav points

- Computation of time-of-arrival limits (min-max)

- Accurate ETA computations

- Trajectory generation and control for advanced weapon delivery profiles

- Trajectory generation to new target redirects

- Mission re-acquisition following unplanned deviations

- Automatic or manual threat avoidance

- IFF time/corridor coordination

- Close metering and spacing control by air traffic control (ATC)

The flight management capabilities provided by the IFTC system are evident even when the aircraft is operating singly, or with several other aircraft in a local area with voice-only commands of a forward air controller (FAC). The IFTC system capabilities are still beneficial in reducing the computations and data entry (workload) requirements that are imposed by present data systems. Operating without benefit of data-linked information, the aircraft can respond in minimum time, and with minimum work effort, to radio contacts with controllers. In summary, the operational benefits derived from the IFTC system will meet the requirements for a quick reaction, precision time-space control system while providing the flexibility for C^2 redirects. The pilot workload is limited to a level that is equal to or less than that presently encountered in either fighters or transports.

Section 5 gives a step-by-step description of the use of the IFTC/Firefly II integration during the execution of a penetration mission with visual, air-to-ground (A/G) weapon delivery.

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3 TACTICAL ELECTRONIC/PROJECTED MAP

3.1 DESCRIPTION

The Electronic Projected Map Display (EPMD) installed in the IFTC simulation cockpit was manufactured by Ferranti, Ltd. of Edinburgh, Scotland. Functionally, the EPMD presents to the pilot a 5-1/2 inch square display that is a combination of two features:

    a. A map image that is projected from a 35-mm filmstrip, and

    b. A computer-generated graphical representation of aircraft position, flight trajectory, miscellaneous tactical information such as threat areas, and the position of other friendly and unfriendly aircraft. The projected and electronic images are optically combined so that they appear to be at the same plane. (Refer to Figure 6.)

Three map modes have been implemented using the EPMD. These modes are selectable by pressing switches on the map control
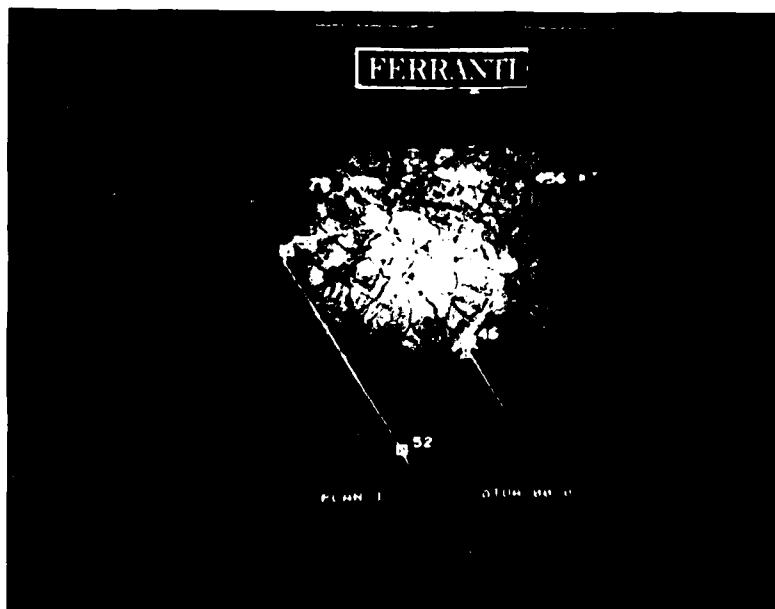
Figure 6. Electronic Projected Map Display

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panel located directly below the HUD. (See Figure 7.) The three map modes are:

a. North-Up. In this mode, the aircraft position is shown by an aircraft symbol that is always at the center of the display. The symbol rotates as the aircraft heading changes, and the map moves under the symbol so that the present aircraft position is at the center of the display. The map is oriented so that north is always toward the top of the display. Figure 8 shows a typical north-up display.

b. Track-Up. This is also a moving map mode, and, like the north-up mode, the aircraft symbol is always in the center of the display. In this mode, however, the aircraft symbol orientation is fixed so that the aircraft heading is always toward the top of the display. Unlike the north-up mode, the map rotates as the aircraft heading changes. This means that map features will be oriented relative to the aircraft as they would appear to the pilot as he looks through the aircraft canopy. Figure 9 shows a track-up display.
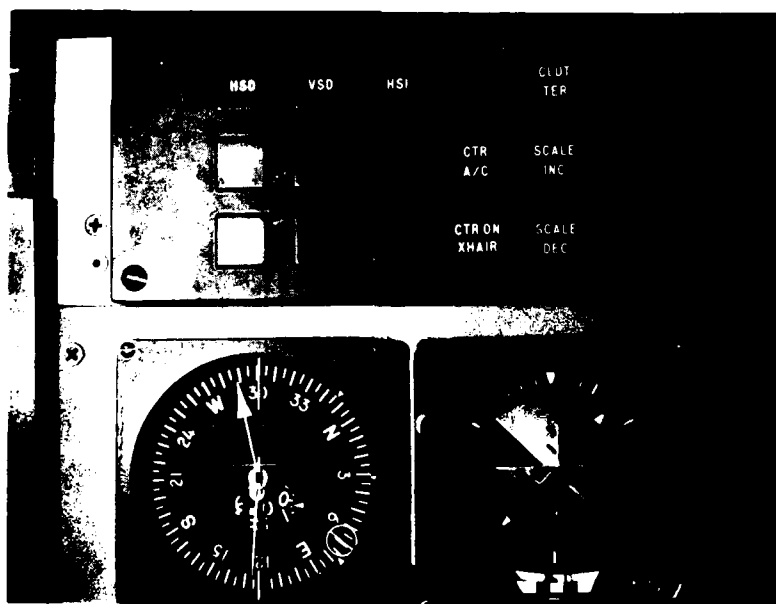
Figure 7. Map Control Panel

Figure 8.   EPMD in North-Up Mode
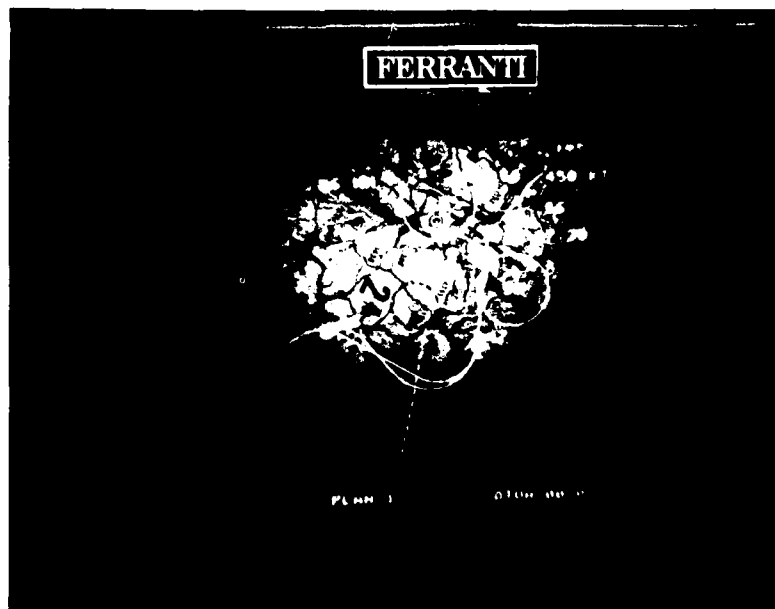
Figure 9.   EPMD in Track-Up Mode

c. Fixed Map. Unlike the two previous modes, this mode is a fixed-map/moving-aircraft presentation, with the map in the north-up position. There are two ways to switch the display to this mode. One is to press the HSD switch on the map control panel. The other is to turn on the map cross-hair (cursor) by pressing the thumb-controlled joystick on the throttle. If the map is in the north-up or track-up mode, it will automatically switch to the fixed-map mode when the map crosshair is turned on. This is done so that the crosshair position will designate a fixed point on the map.

When the fixed-map mode is entered, the map will be centered at the present aircraft position, and the aircraft symbol will move toward one edge of the display area. If the map remains fixed long enough, the aircraft symbol may completely disappear from the display.

The map can be repositioned at any time to re-center the aircraft position by pressing the CENTER ON A/C switch on the map control panel.

Another switch on the map control panel is used only in the fixed-map mode. This switch, CENTER ON XHAIR, can be used to reposition the map so that the display center will be equal to the position of the crosshair when the switch is pressed. This capability is useful if the pilot wishes to examine a part of the map that is remote from the present aircraft position. The map can be moved to position any point on the map at the center of the display. Figure 10 shows the EPMD in the fixed-map mode, with the crosshair on.

In all map modes, one of three map scales can be selected. The scales are specified as the distance across the display (top-to-bottom or left-to-right) and are 72, 36, or 18 nautical miles. Map scaling is controlled by the SCALE INC (increase), and SCALE DEC (decrease) switches on the map control panel. Pressing the SCALE INC switch will increase the apparent size of the map (switch map display coverage from 32 nm to 16 nm, for example).

A fourth, non-map, mode can be displayed on the EPMD. This mode is selected by pressing the VSD (vertical situation display) switch on the map control panel. In the VSD mode, a plot of altitude (vertical) vs along-trajectory distance (horizontal) is presented. The vertical axis at the left of the display represents the present aircraft position. As the aircraft proceeds along the trajectory, the plot translates from right to left on the display, always showing the altitude profile for the next 80 nautical miles along the trajectory. The desired aircraft altitude at any time is the point at which the plot intersects the vertical axis. the actual aircraft altitude is displayed as a pointer on the vertical axis. In the VSD mode, the map film is driven to a blank frame to provide a plain background for the vertical situation display. Figure 11 shows the EPMD in the VSD mode.

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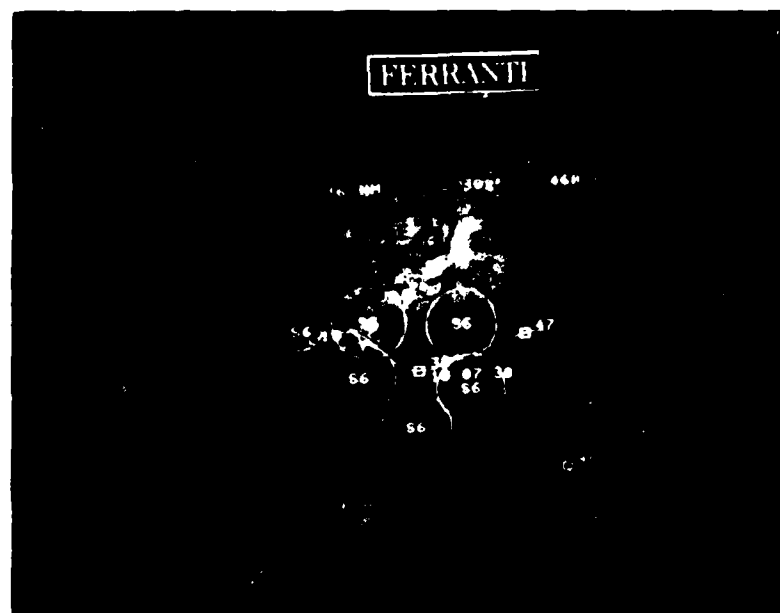
Figure 10.   EPMD in Fixed Map Mode
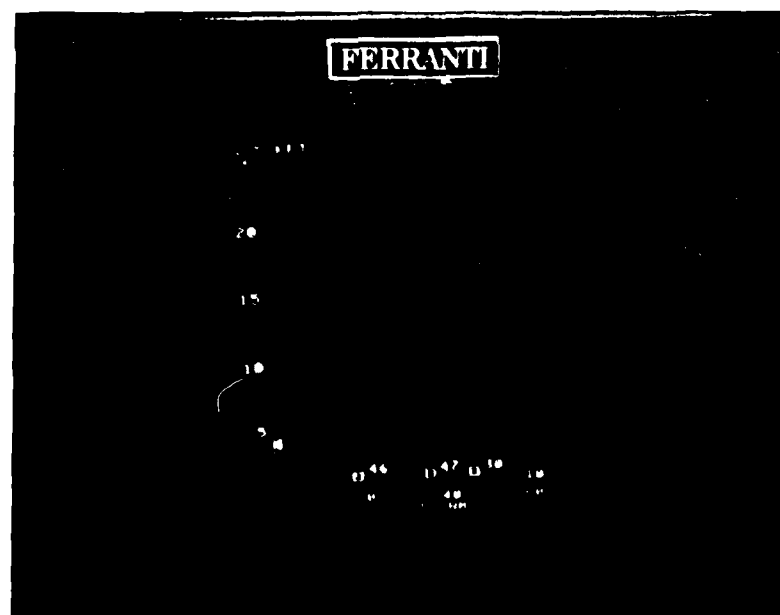
Figure 11.   EPMD in VSD Mode

3.2 GRAPHICS SYMBOLOGY

Figure 12 shows the various symbols that are used on the computer-generated map overlay.

Two-digit identifiers are used with the waypoint, IP, and target symbols to "tag" each symbol. A two-letter identifier is placed at the center of each threat/avoidance area to indicate a surface-to-air missile (SAM) or anti-aircraft (AAA) threat.

The aircraft symbols rotate on the display to indicate aircraft heading. Two digits are placed next to each friendly or unfriendly aircraft symbol to indicate the approximate aircraft altitude in thousands of feet.

3.3 MAP FILM FORMAT

The map film is created by photographing standard navigation charts. In producing the film, charts of different scales are photographed onto different parts of the film. Scale changing is accomplished by accessing a different part of the film, not by changing the optical magnification.

PRESENT AIRCRAFT POSITION *

WAYPOINT , IP

TARGET

UNFRIENDLY AIRCRAFT *

FRIENDLY AIRCRAFT *

THREAT / AVOIDANCE AREA
(RADIUS IS VARIABLE)

* ORIENTATION OF AIRCRAFT SYMBOLS IS
VARIED TO INDICATE AIRCRAFT HEADING
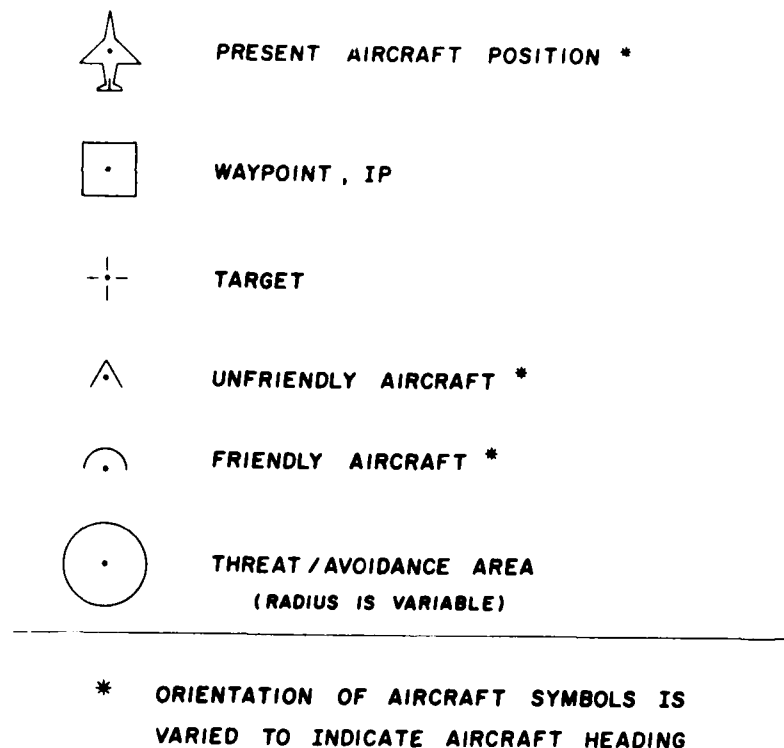
Figure 12. Graphics Overlay Symbology

Three map scales are used in the IFTC simulation: 1,000,000:1; 500,000:1; and 250,000:1. The scales correspond to map display coverage (top-to-bottom) of 72, 36, and 18 nautical miles, respectively. The 250,000:1 scale uses special decluttered charts that contain only major map features and very little alphanumeric information.

The geographical areas covered by the map are defined as a number of rectangles. Each rectangle area at a particular scale is divided into a number of east-west oriented strips of a fixed width. The strip width is related to the scale as follows:

$$
\begin{array}{ll}
1,000,000:1 & 2° \\
500,000:1 & 1° \\
250,000:1 & 0.5°
\end{array} \Bigg\} \quad \text{latitude}
$$

Refer to Figure 13.

The strips are laid out along the length of the film in an orderly fashion. For each rectangle, the distance between the start of successive strips is kept constant, and the strips are laid out in order with the most southerly nearest the beginning (left) of the film.
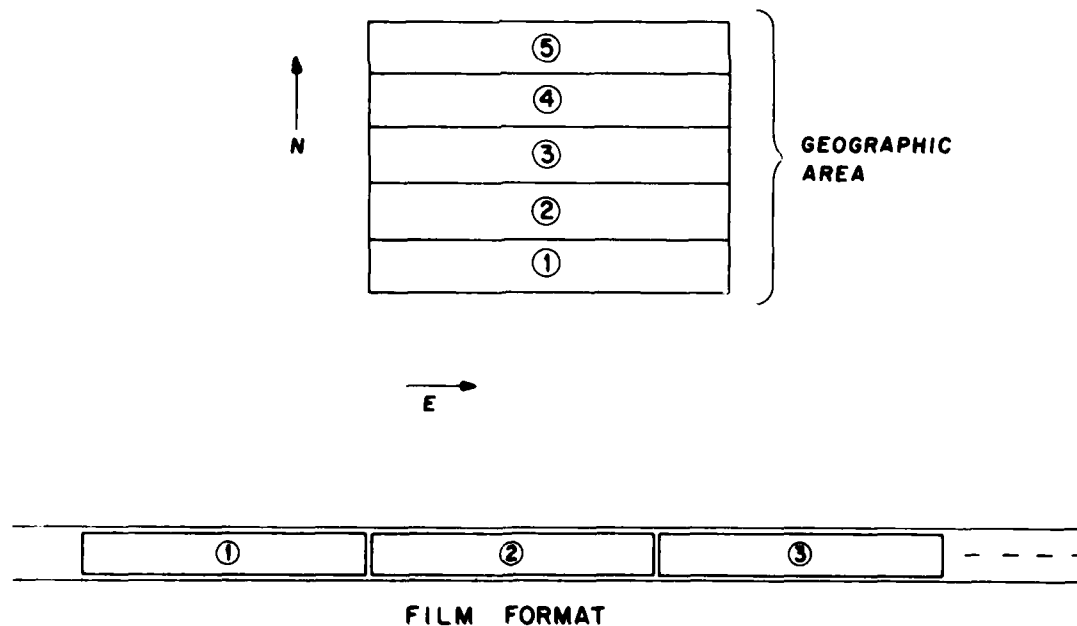
Figure 13. Map Film Format

The basic chart material used for the production of the filmstrips is either Transverse Mercator Projection or Lambert Conformal Projection. Over the area of map used for any one photograph, both of these projections can be considered to have a latitude/longitude grid in which lines of latitude are arcs of a circle with a common center (the projection of the pole) and lines of longitude are straight lines which radiate from the same common center.

During the photographic process, the projection is manipulated into the form of a Plate Caree Projection. In this projection, lines of latitude and longitude form a grid of orthogonal straight lines. It is arranged that the lines of latitude are parallel to the film axis (length), and the lines of longitude are perpendicular to the film axis. Using this projection means that, in the northern hemisphere, there will be a slight stretch in the scale factor north of the strip centerline and a slight compression below the strip centerline. This departure from conformality in the projection is not detectable visually, and does not lead to positional errors, as the drive computer uses this new projection equation.

3.4 EPMD SYSTEM INTERCONNECT

Figure 14 shows the system hardware interconnections for the EPMD. Both the film drive channel and the graphics overlay channel are controlled by the PDP-11/70 "mission" computer. This computer supplies the present aircraft position, heading, and speed information to the map. It also sends trajectory data to the graphics processor, and tells the processor what features to draw on the overlay.

The data flow from the PDP-11/70 is through a PDP-11/20 controller to a PDP-11/03 microcomputer. The software in the PDP-11/03 controls both the film drive and graphics interfaces, which are physically located in the PDP-11/03 chassis. The following paragraphs describe the film drive and graphics channels in detail.

3.4.1 Map Film Drive

The projected map film drive module contains a reel that holds up to 57 feet of 35-mm color film. The film is positioned by three servo channels, designated X, Y, and $\emptyset$. The X channel positions the film along its length, the Y channel positions across the film width, and the $\emptyset$ channel rotates the film about the point, determined by the X and Y film positions.

The X, Y, and $\emptyset$ positioning information is sent to the map display in digital form. Four 16-bit words are used to define the film
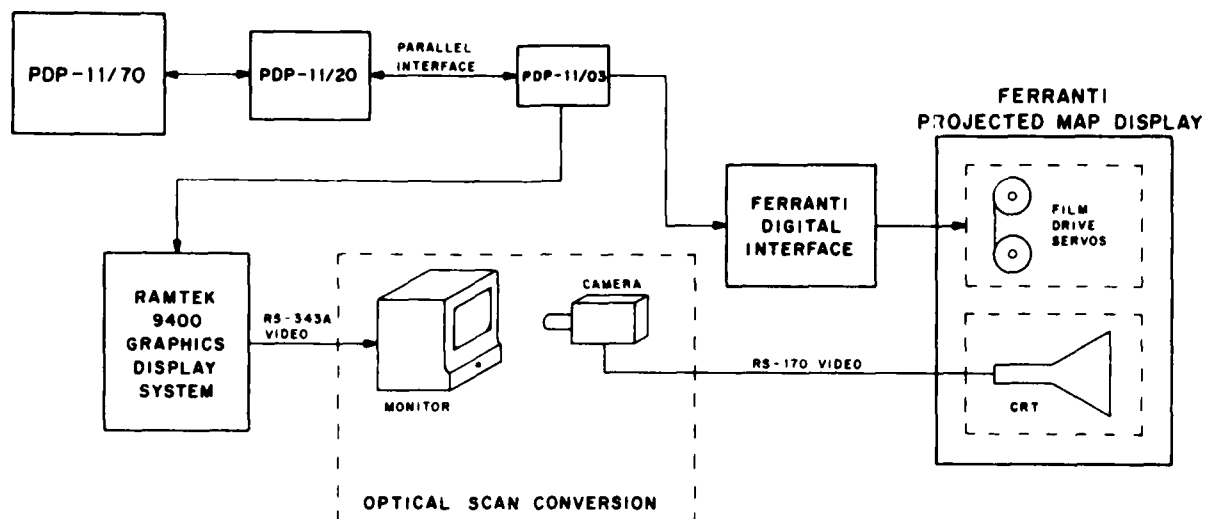
Figure 14. Map Display/Graphics System Interconnect

position: two for X, one for y, and one for $\emptyset$. Twelve bits of each word are used for positioning data. The four most significant bits of each word are used for word identification.

To achieve a short access time to any part of the film, the film can be slewed at speeds up to 8 feet per second. This gives strip changes in less than one second, and typical scale changes in less than three seconds.

3.4.2 CRT Circuitry

The computer-generated information that overlays the projected map image is generated by a Ramtek 9400 Graphics Display System. The PDP-11/03 that supplies the Ferranti map film positioning data also drives the Ramtek 9400.

The video output from the Ramtek is a 512-line, repeat field signal (RS-343A). This means that all 512 lines of the display are refreshed at a 60-Hz rate to eliminate display flicker. The input to the Ferranti video circuitry is a standard 525-line, interlaced video signal (RS-170). In this format, the odd and even lines of the display are refreshed alternately at a 60-Hz rate, which gives a total display refresh rate of 30 Hz.

In order to make the Ramtek output compatible with the Ferranti input, an optical scan conversion is performed. The repeat field video signal is displayed on a monitor, and a monochrome camera changes the monitor image to an interlaced video signal. This signal is applied to the Ferranti video input.

The video input is displayed on a high-intensity, three-inch CRT inside the map display unit. The computer-generated information is scaled, translated, and rotated to maintain registration with the projected map image. Separate brightness controls are provided on the EPMD for both the CRT and the projected map image.

4   MISSION DATA TRANSFER SYSTEM

Figure 15 shows the elements of the Data Transfer System (DTS): the ground-based system, the data module, and the aircraft receptacle.

4.1   DESCRIPTION

The Data Transfer System is a user-oriented, multi-purpose computer system providing instant access to the aircraft computer for accurate retrieval of mission planning data and for data storage of in-flight data for post-mission analysis. A ground-based computer loads key mission data into a pocket-sized Data Transfer Module (DTM). A crew member carries the module to the aircraft, inserts it into the aircraft receptacle, and, with one keystroke, initializes and loads a comprehensive array of operational information required for the mission. At the end of the mission the process may be reversed, with the module returned to the ground-based computer where all post-flight data, including maintenance data, may be extracted, displayed, and evaluated.

The current system has been flight tested and qualified for in-flight use, having been selected by the USAF for the F-4E fighter and the RF-4C reconnaissance aircraft.

4.1.1   Data Transfer Module

The Data Transfer Module, shown in Figure 16, is sized at 3.3 in x 6.0 in x 0.7 in to allow it to fit into any flight suit pocket or helmet bag. The present unit has a memory capacity of 8,196 x 16 bit words and it is expected that new memory technology will allow expansion of the module to 128k words. The module is designed to operate in the temperature range of -54°C to +95°C, and up to 100% humidity, while withstanding shocks to 50 g's. The Data Transfer Module meets the general requirements for MIL-E-5400R, Class II avionics. The memory in the module is maintained by a self-contained battery with an expected life of 9 months.

4.1.2   DTM Receptacle

The DTM Receptacle, shown in Figure 17, is cockpit mounted and accepts the DTM. The receptacle is typically connected to the airborne computer via an RS232 line or a 1553 data bus. For the IFTC program, the receptacle was wired to the simulation computers via an RS232 line. The receptacle allows automatic transfer of the DTM data at the request of the host computer. Receptacle and module keying prevents unintentional, backward insertion into the receptacle. A single button, labeled PUSH REL, allows the module to be released. A small, recessed pushbutton switch on the module allows the battery circuit to be interrupted and the module data to be scrambled, if required for security reasons.
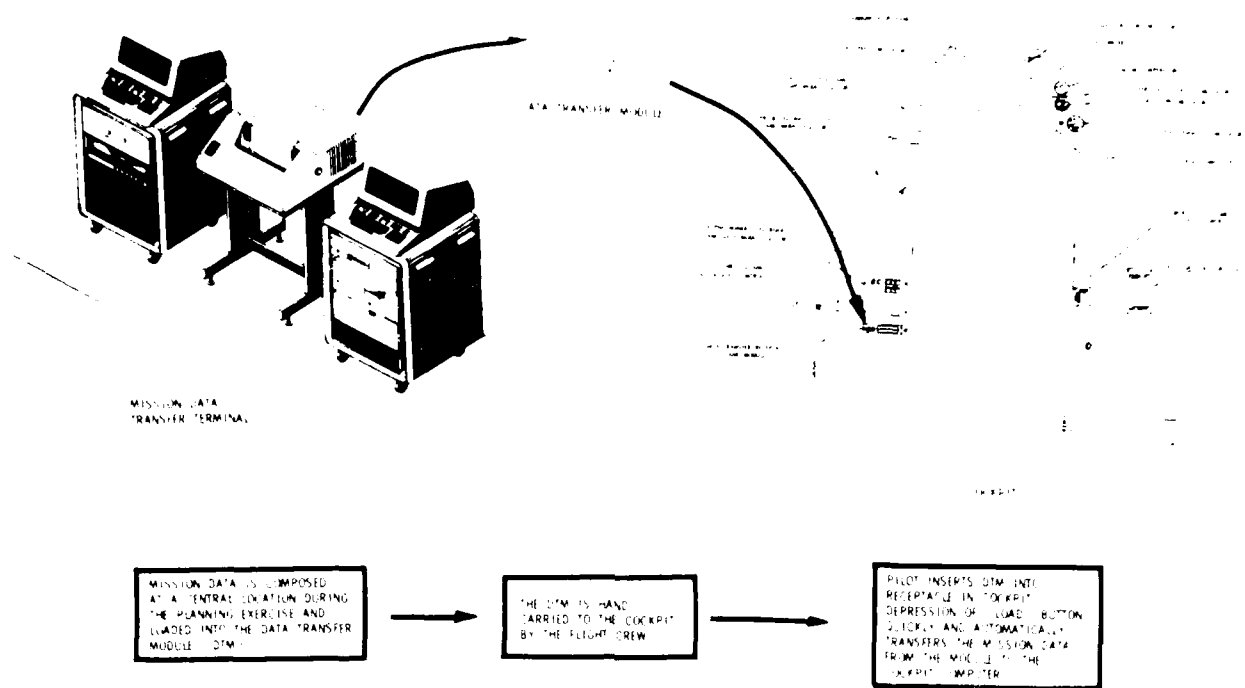
Figure 15. Data Transfer From Terminal to Cockpit
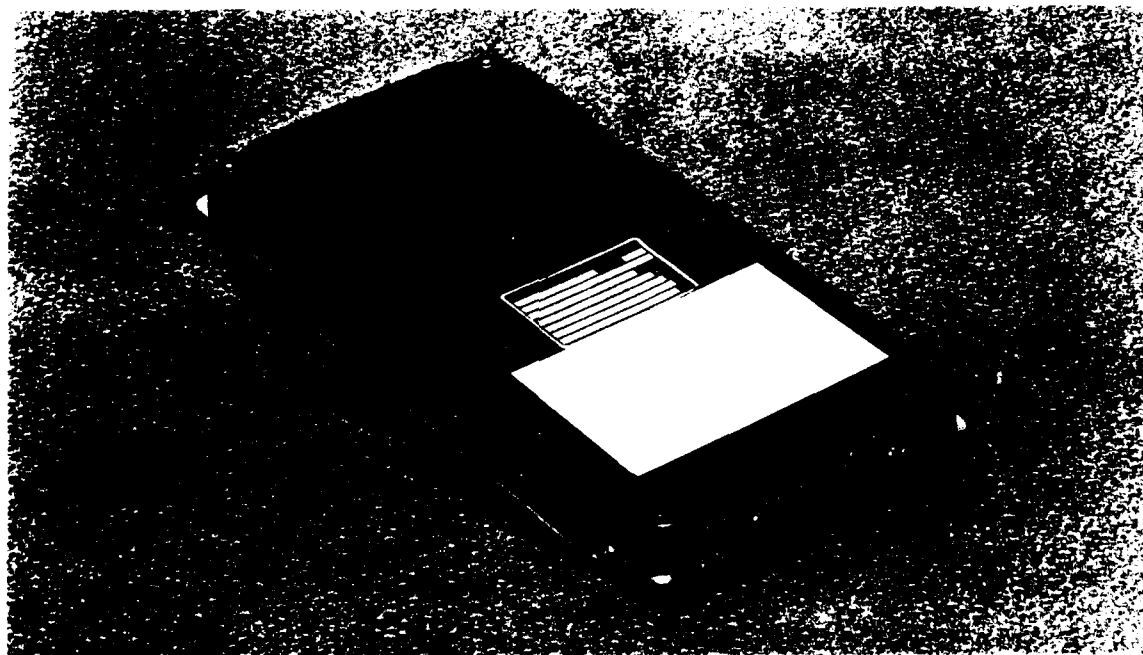
Figure 16. Data Transfer Module
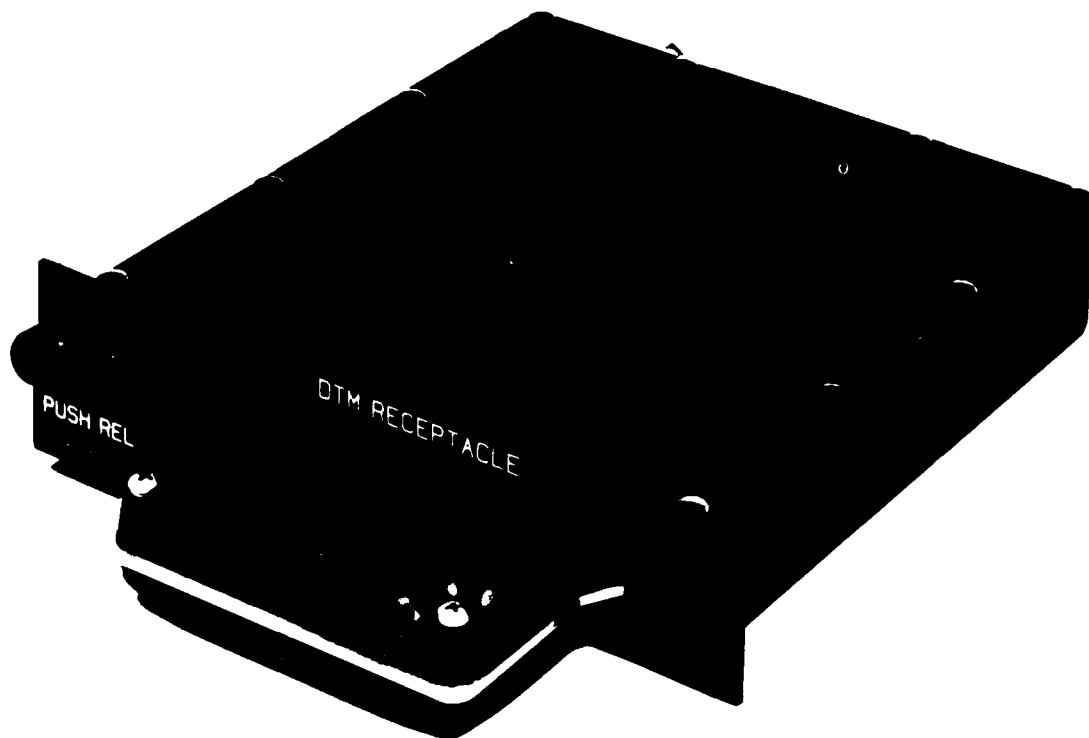
Figure 17. DTM Module Inserted in Receptacle

4.1.3 Ground-Based System

The ground-based system, shown in Figure 18, consists of a
standard 1000 series Hewlett-Packard general purpose computer
presently in Air Force inventory. Other ground-based components
are a disc drive, two CRT display stations, a line printer, and
paper-tape reader. The terminals can direct user inputs from
multiple sources (tape and keyboard), while providing disc stor-
age, CRT display, and hard copy. All classified data may be
stored on a removable disc. Two users may operate the system
simultaneously, and the system software contains maintenance
diagnostics which test the terminal and the module prior to load-
ing data. The system is packaged in watertight, shockproof cases
for tactical transportability.
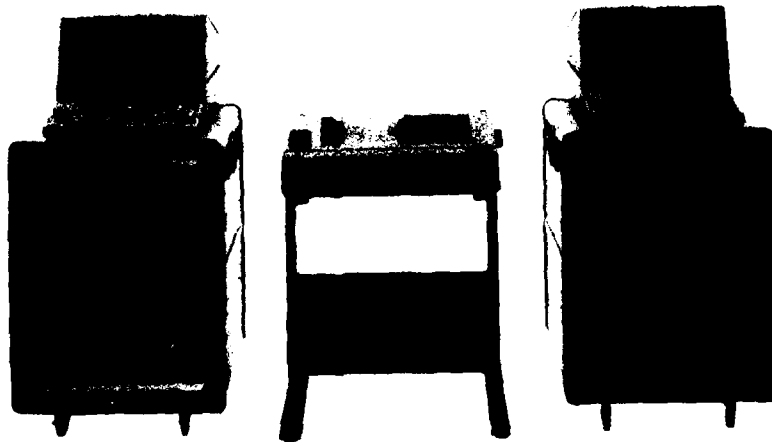
Figure 18. Mission Planning System

4.2 MISSION PLANNING

For the IFTC Development Program pilot testing, the Data Transfer System was installed near the simulator cockpit, and the pilots were trained to use the system for mission planning and modification. A subset of the software developed for the ARN-101 system was used for the IFTC program. As a result, not all of the complete capability of the system was available. This fact was reflected somewhat in the pilots' comments with respect to the inability of the system to manipulate certain types of data.

The pilots (in pairs) were given about 15-30 minutes of classroom instruction for hands-on operation. The pilots observed the instructor using the system for about 30 minutes, after which both were turned loose to operate the system themselves. The system software -- which controls the pilot-system interface, primarily those instructions displayed on the terminal -- was written to provide a high degree of self-instruction. Each page appearing on the terminal CRT provides a set of instructions in menu-like fashion, and a corresponding one-of-eight function key is depressed on the keyboard to execute the function.

Within 30-60 minutes each pilot felt comfortable enough with the system to begin creating new missions or modifying existing ones with minimal consultation with the instructor. Figure 19 shows a typical instruction page on the Data Transfer System. Figures 20 and 21 show pages 1 and 2 of a typical waypoint data entry page, and Figures 22 and 23 show pages 1 and 2 of a typical target data entry page. The format of each page has been made consistent with the corresponding page on the Status Display in the cockpit.

The DTS operating system software has been designed to allow full flexibility for defining display formats to satisfy varying requirements.

After displaying waypoint, target, IP, and other required data, the pilot constructs his flight plan by arranging the mission points in proper order on the flight plan page. This page is shown in Figure 24.
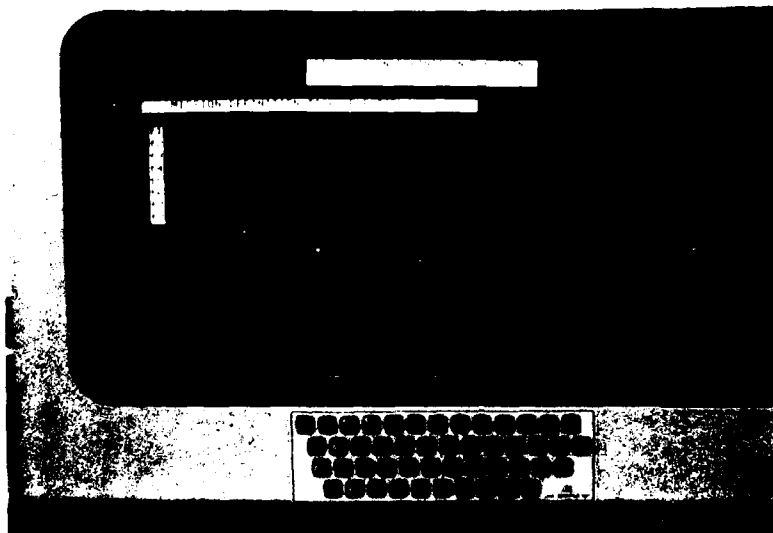
Figure 19. Typical DTS "Select" Page
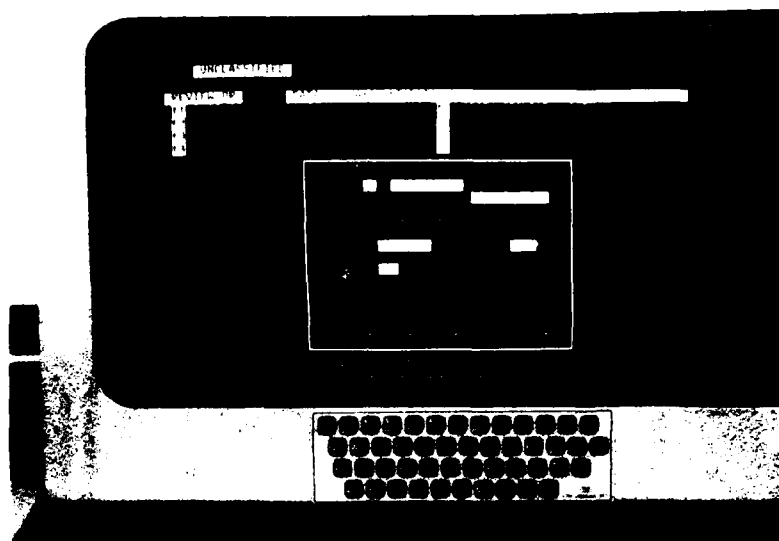
Figure 20. Page 1 of Waypoint Data
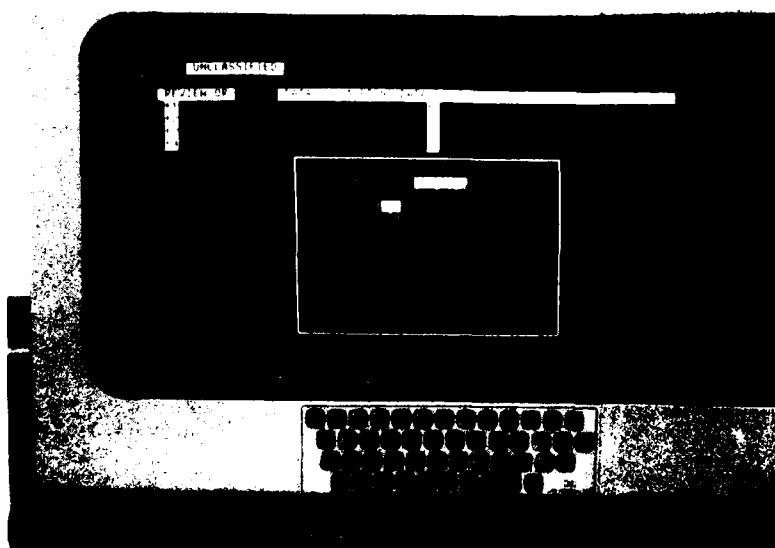
Figure 21. Page 2 of Waypoint Data

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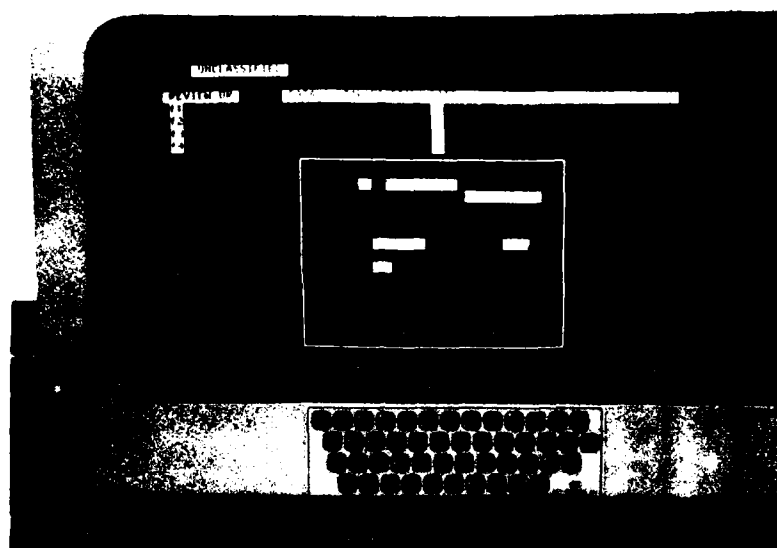
Figure 22.   Page 1 of Target Data
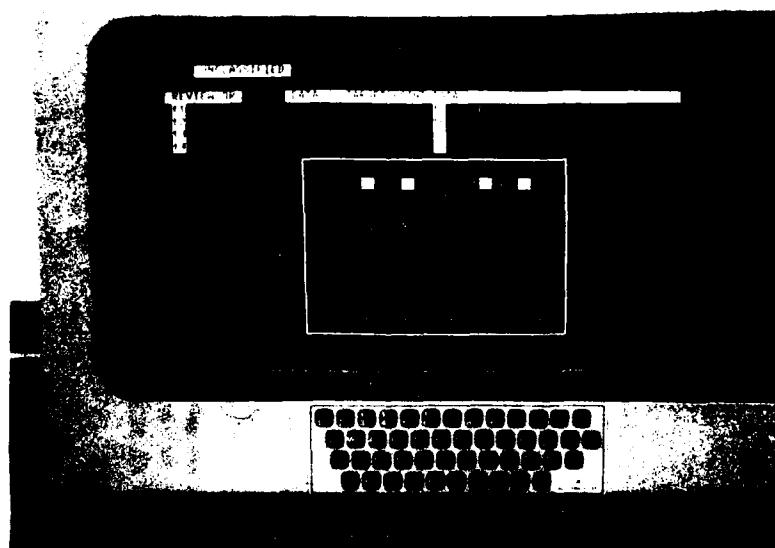
Figure 23.   Page 2 of Target Data

33
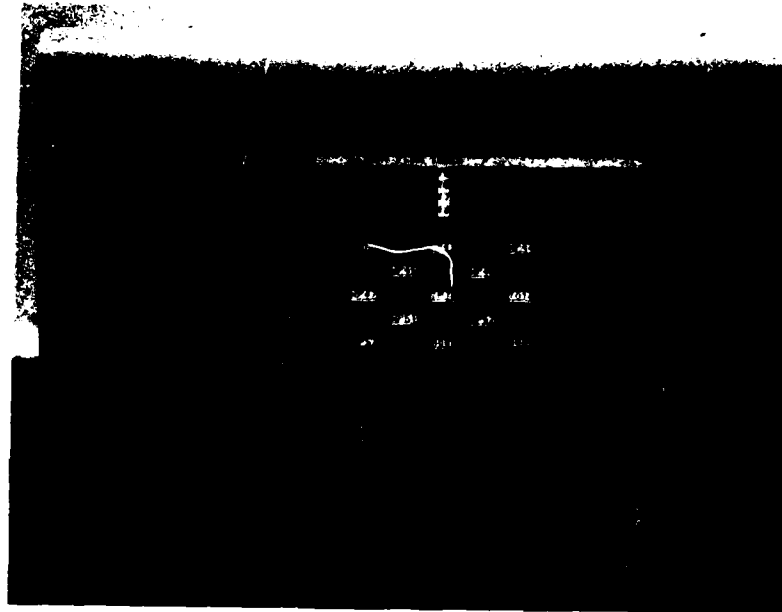
Figure 24.   DTS Flight Plan Page

Upon completion of flight planning, the pilot may load the module and print the mission. Loading the module is a simple and fast operation, and the pilot may request a module self-test before loading. The pilot may, at any time, also request a print-out of his mission which is on a handy-sized 8-1/2 x 5-1/2 form for easy manipulation. Figure 25 shows the first two pages of a typical print-out.

MISSION DATA
TRANSFER SYSTEM

MISSION ID: MISB04

MISSION LITTLE JOHN

MISSION PRINTED
11:55 AM TUE., 27 JAN., 1981

UNCLASSIFIED

FLIGHT PLAN INDEX
UNCLASSIFIED
LITTLE JOHN   PAGE 1 OF 2

```
:  1
:  --\    PL1           WP40           WP41          :
:  2
:  -->           TP30           TG10                 :
:  3
:  -->    IP31          TG11           WP42          :
:  4
:  -->           WP40           0000                 :
:  5
:  -->    0000          0000           0000          :
:
:        PLAN DATA PAGE 1 OF 2                        :
:
:         ^1     ^2      ^3      ^4      ^5           :
```

UNCLASSIFIED

Figure 25. MDTS Printout of Flight Plan

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5 WEAPON DELIVERY

Most high-performance, tactical aircraft are designed to deliver weapons. This may be done while in an offensive or defensive posture, may involve the delivery of bullets, rockets, or bombs, and the delivery may be air-to-air or air-to-ground. The obvious measure of the success of the aircraft and weapon delivery integration is the ability to destroy the target and avoid being destroyed by the target defenses. The appearance of high-speed, digital processors in the cockpit has made it possible to implement the integration of fire control technology with flight control technology as a means of improving this measure of success.

5.1 FIREFLY II WEAPON DELIVERY

Firefly II was a joint AFAL/AFFDL-sponsored program to investigate the potential benefits of the integration of director fire control with modern flight control technology. Air-to-air gunnery, air-to-ground gunnery and bombing were the primary weapon delivery tasks investigated. Emphasis has been on assisting the pilot in the terminal phase of weapon delivery where precision control is critical; this would occur after the pilot has accomplished the necessary air combat maneuvering to acquire the target. The details of the Firefly integrated approach are described in references [1] and [2]. The IFTC Development Program has investigated the advantages afforded by integrating the IFTC trajectory generation and time control concepts with the Firefly II air-to-ground bombing techniques. In particular, the emphasis has been to help the pilot fly to a properly computed offset point from which the Firefly II weapon delivery maneuver is initiated.

The remainder of subsection 5.1 summarizes the Firefly II guidance concept.

Figure 26 shows the principal bombing geometry parameters, assuming zero wind and target velocities. The assumption of zero wind and target velocity is made only in the interest of simplifying the explanation and is not an assumption made by the complete guidance derivation. $\bar{P}$ is a point displaced vertically above the target toward which the aircraft velocity vector must be directed at the time of release to achieve a hit. $\bar{P}$ is commonly referred to as the "air-mass aimpoint". $\bar{G}$ is the distance corresponding to the gravity drop time of fall of the bomb. If the aircraft is to turn at constant rate $\bar{w}$ from its present position to the bomb release point, the vector relationship among the parameters is

$$\bar{S}_v \times \bar{S}_p = \frac{R_p^2 - R_r^2}{2 \, V_a R_p} \, \bar{w}$$

(1)
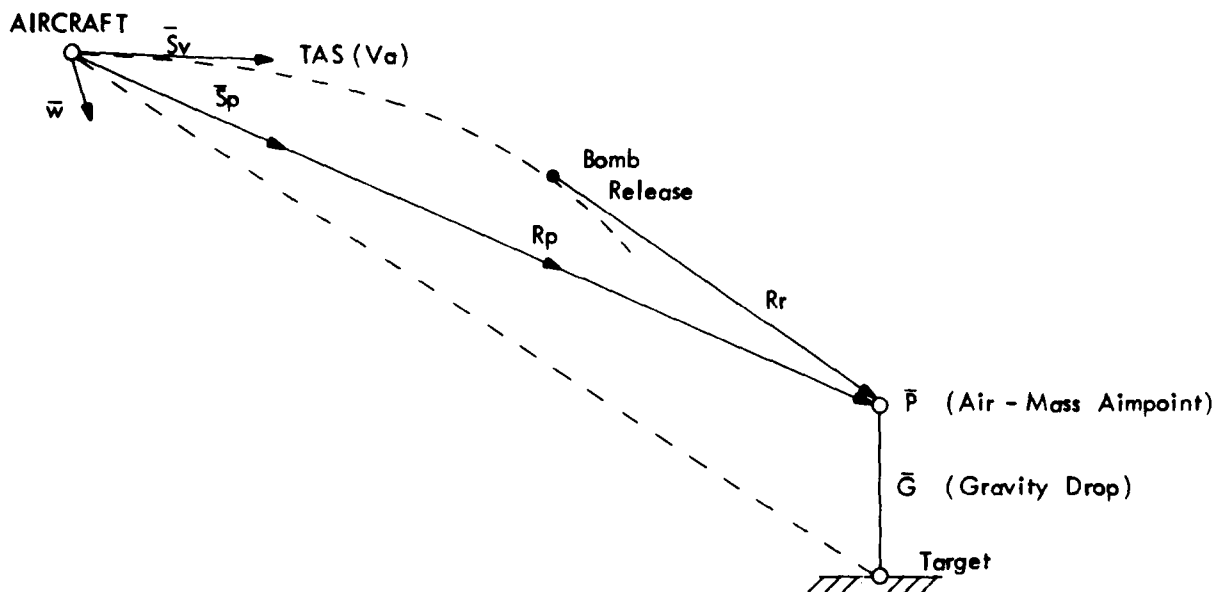
Figure 26. Principal Bombing Parameters

Rather than imposing a maneuver-fixed value of $\bar{G}$, resulting in a fixed angular delivery rate, $\bar{w}$, the approach taken by Firefly was to allow the release conditions to be determined as a function of turn-rate magnitude, $/\bar{w}/$. The pilot controls the turn-rate magnitude by controlling the g loading on the aircraft, which indirectly determines $\bar{G}$, and consequently $\bar{P}$. The roll attitude of the aircraft required to fly to the release condition at constant angular rate is determined from the basic guidance equation (1), and an appropriate roll rate command is issued to the flight control system to achieve the desired roll attitude.

The expected ballistic range at the time of release is displayed to the pilot, digitally, on the HUD.

For the Firefly II design the pilot's control task is to adjust the aircraft lift acceleration to provide an acceptable value of release range. The corresponding g level is then maintained and the roll attitude will be essentially constant to weapon release. Bomb release is automatic.

For the integration of Firefly II and IFTC, the Firefly II control task was modified somewhat. This change in delivery technique is described in detail in the next section.

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5.2 IFTC/FIREFLY II INTEGRATION

The primary emphasis for the IFTC/Firefly II integration is to allow the pilot to specify certain delivery, release, and egress parameters and use those parameters to determine the position of the offset or entry point (E/P) with respect to the target. The E/P is sometimes referred to as the attack initiation point (AIP), and is the point at which IFTC path guidance passes off control to the Firefly II guidance, and the actual, high-g, maneuvering weapon delivery phase begins.

In particular, the pilot may specify the primary parameters of minimum penetration distance to the target, desired delivery and egress loading g's, and a not-to-exceed altitude. The pilot may also specify such secondary parameters as the angle-off value of the pop-up maneuver (total track angle change from start of maneuver at the E/P, to the release point), the E/P altitude and the maximum egress A/C roll angle. In each case, default values are used if not specified. For those situations requiring a multiple bomb, ripple drop, the pilot may specify the azimuth of the desired impact pattern for best effect.

The target position, bomb type, and delivery parameters determine the release point and the E/P. The E/P position coordinates are computed by the IFTC algorithms and are used by the IFTC guidance laws for proper aircraft steering command generation.

The air-to-ground weapon delivery maneuver is shown in Figure 27, and consists of three phases -- ingress, delivery, and egress. The IFTC/Firefly II integration design affects each phase and each will be discussed in the following paragraphs.
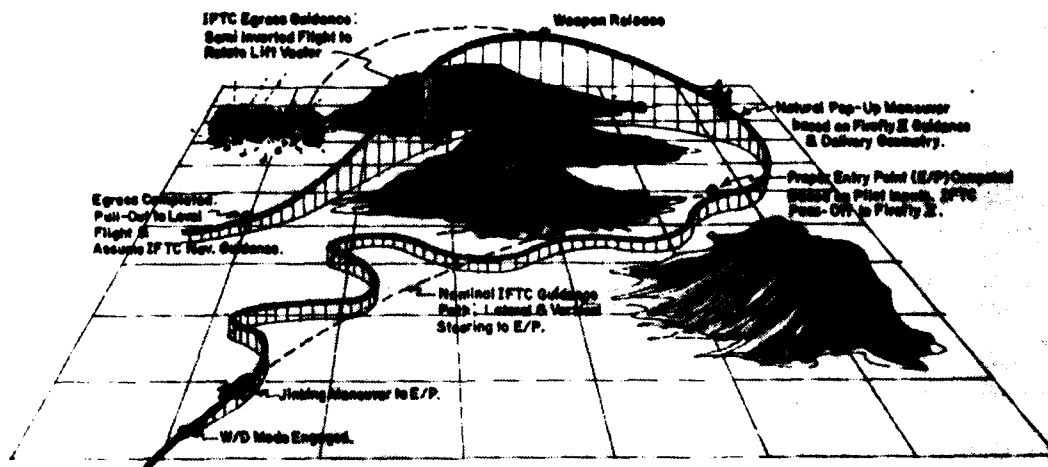
Figure 27. Integrated IFTC/Firefly II Air-to-Ground Weapon Delivery

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5.2.1 Ingress

The goal of the ingress phase is to position the aircraft properly at the E/P for starting the Firefly II delivery maneuver. In the presence of target defenses the ingress phase will be flown at low level. It is assumed that the initial target acquisition has occurred and that the aircraft is approximately 60-80,000 feet from the E/P, at the start of ingress phase. The pilot has specified the expected loading g's to be applied during weapon delivery and egress maneuvers, as well as the minimum penetration to target distance, which occurs after weapon release. These parameters are selected as a function of the existing target defenses and pilot experience. At his option the pilot may specify a not-to-exceed altitude in the pop-up maneuver and the maximum roll angle for inverted flight during egress. This will be discussed in 5.2.3.

All pilot selected parameters may be determined during mission planning and loaded into the data transfer module for later entry into the flight computer. Capability for changing these parameters was provided through the simulation computer terminal. Changes in the cockpit could be made through the weapons control panel. The pilot may also specify the anticipated airspeed and altitude at the E/P, but has full freedom to change these by piloting inputs during ingress.

Figure 28 shows the HUD symbology used in the ingress mode. Table 1 defines each symbol. Figure 29 shows the HUD in the initial phases of ingress.

The IFTC trajectory algorithm accepts all inputs and computes an initial estimate of the E/P position. The E/P position with respect to the target is affected by both the pre-specified delivery parameters as well as the piloting control inputs during the maneuver. Appendix A describes in detail the relationship between the E/P position and the delivery parameters. It is important to note, however, that the E/P coordinates are in an aircraft along-track, cross-track coordinate frame with respect to the target. The pilot has complete freedom to choose his attack heading. The attack heading is not an input parameter in the sense that the pilot is required to preselect it, but is controlled by establishing the aircraft heading at the start of the ingress phase.

A right-hand or left-hand approach to the target during the delivery phase may be forced simply by placing the target on the right side or left side of the aircraft track vector as the ingress is inititated. The decision may be reversed during the ingress maneuver by changing the aircraft heading to reposition the target to the opposite side of the aircraft. This assumes sufficient time-to-go to the E/P, however, to allow maneuvering time and distance. See Figures 30 and 31 for an example of a right-hand and left-hand delivery approach.
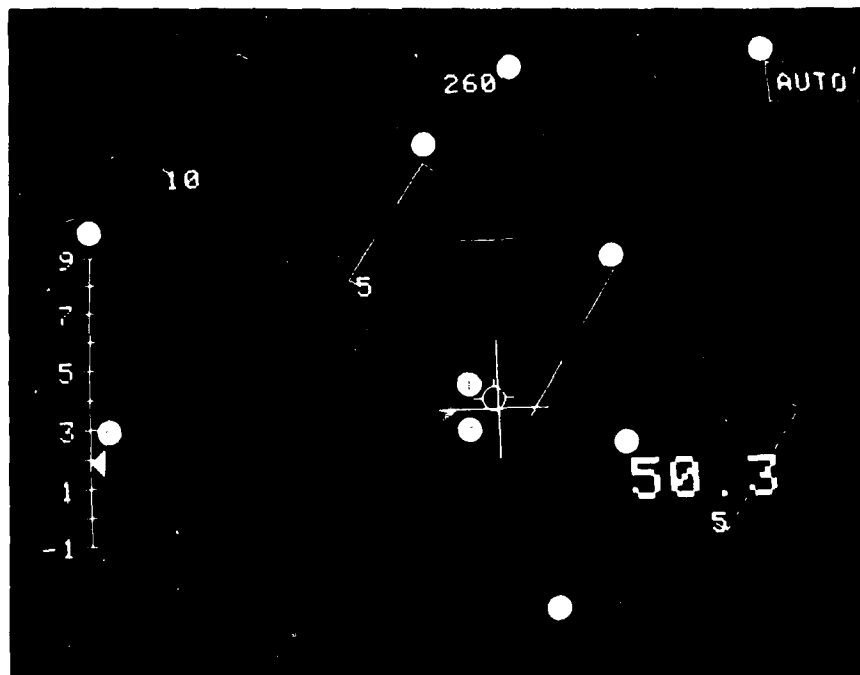
Figure 28. Ingress HUD Symbology

TABLE 1. HUD SYMBOLOGY LEGEND

1. Flight Path Market (FPM)
2. Horizon Reference
3. Pitch Ladder
4. A/C Heading/Track
5. G Scale
6. A/C G's
7. Pitch-Roll Flight Director
8. Autopilot Mode
9. Pull-Up Cue
10. Time-to-Go (To Offset Point)

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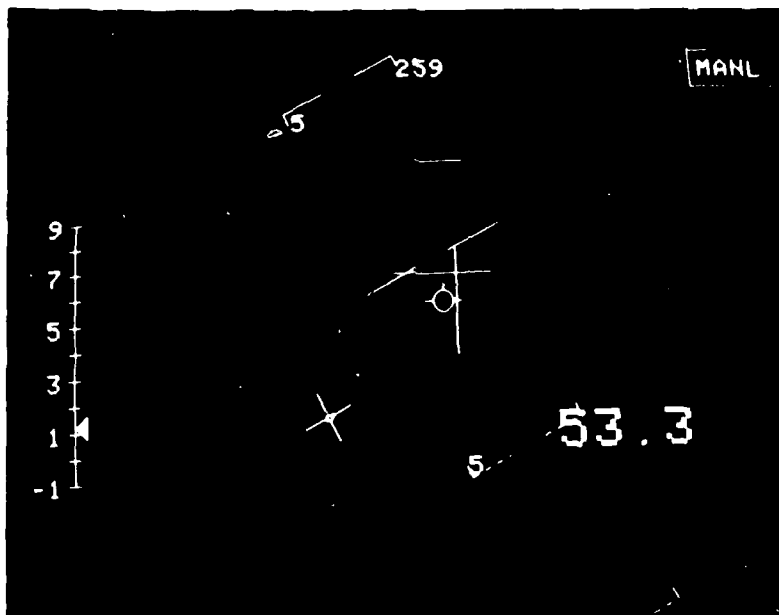
Figure 29.   HUD - Initial Phase of Ingress
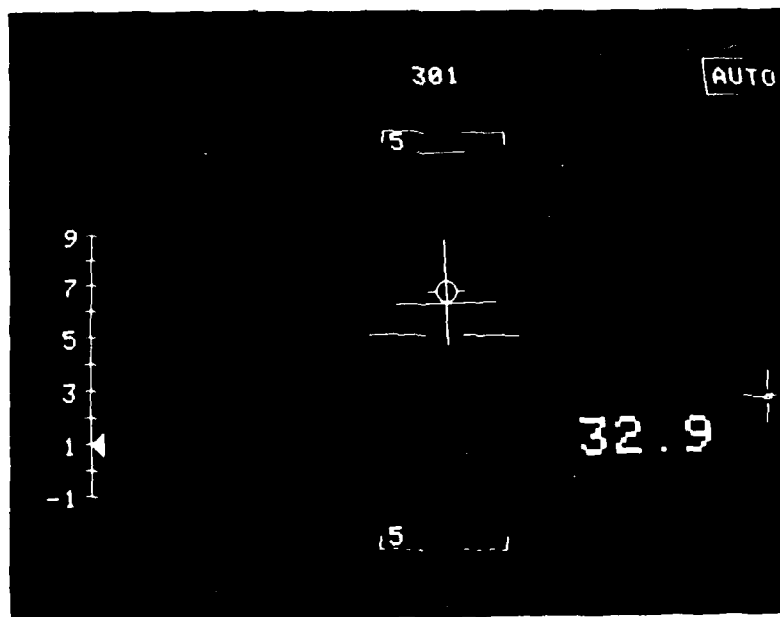
Figure 30.   HUD - Right-Hand Delivery
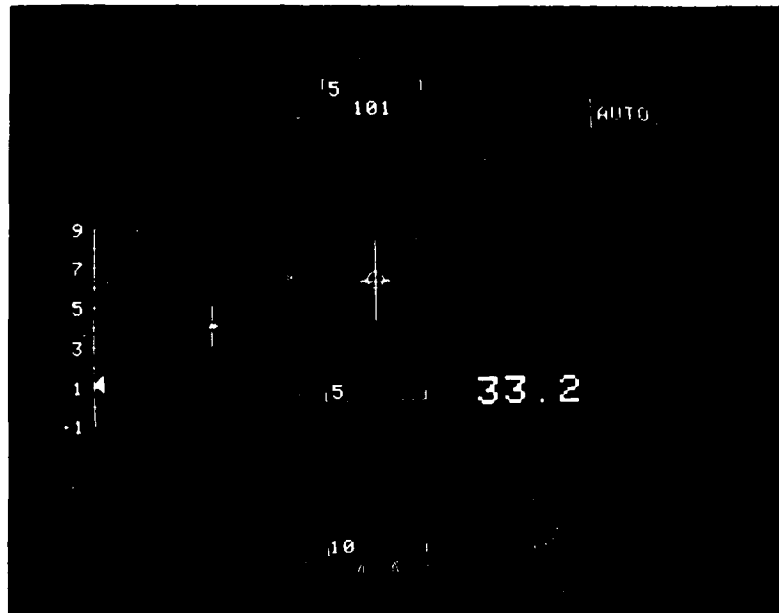
Figure 31.   HUD - Left-Hand Delivery

In summary, the pilot has complete freedom to control the ingress and attack heading by manually controlling the aircraft heading during the initial part of the ingress phase. This decision is made on the basis of enemy defenses, ground terrain and other related factors.

Once the ingress heading is established, the E/P position remains essentially fixed, varying possibly by 500' to 2000' if the aircraft speed or altitude change from the initial values.

The pilot has several options for control of his aircraft during the ingress phase: fly a jinking, maneuvering approach to the E/P; follow the pitch and roll flight director cues on the HUD, for proper manual steering to the E/P; or engage the automatic flight control system to control the aircraft in pitch and roll to arrive at the E/P at the desired altitude.

The ingress trajectory algorithm makes provision for piloting inputs in the form of jinking or otherwise evasive maneuvers. For relatively longer distances from the E/P the pilot has more latitude or freedom for making these maneuvers. As the distance to the E/P shortens, the lateral maneuvers become more restricted. A good analogy is to consider the E/P at the neck, or narrow end, of

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a funnel, with the mouth, or wide part of the funnel, extending away from the E/P in the direction of the aircraft. The aircraft has maneuvering freedom as long as the maneuvers stay within the funnel walls. As the aircraft approaches the E/P, the wall of the funnel narrows, restricting the allowable lateral movement.

As the aircraft approaches the funnel wall during a jinking maneuver the pilot is given a warning on the HUD in the form of a flashing break-X positioned over the flight path marker (velocity vector symbol). The flashing break-X is the indication to the pilot that he should break off the jinking maneuver and either follow the flight director cues or switch to the auto-flight mode for automatic control of the aircraft back to the desired trajectory to the E/P. If the pilot ignores the warning and continues the evasive maneuver (circumstances may force him to) the break-X will stop flashing and become steady. This indicates that the funnel wall has been penetrated and the weapon delivery maneuver should be aborted. Figure 32 shows a solid break-X condition.

The criteria for determining the abort alert boundaries are based upon the required bank angle and turn radius necessary to recover from the jinking maneuver and fly to the E/P position, as well as the range and relative bearing to the target. The steering logic and switching curve derivation is discussed in more detail in Appendix A.
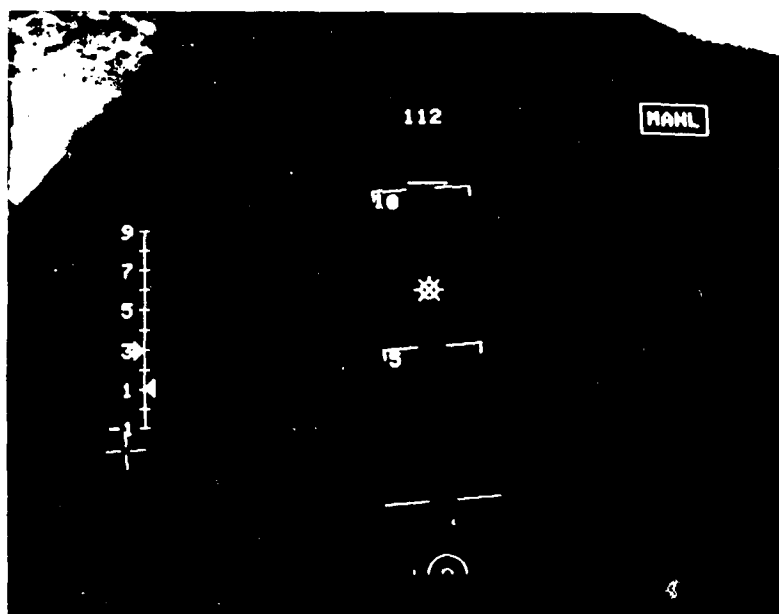
Figure 32. HUD - Break-X, Abort Delivery

The second option allows the pilot to manually control the aircraft during the ingress maneuver by following the pitch and roll steering cues on the HUD. Jinking at any time is still possible.

The third option allows the pilot to select automatic pitch and roll aircraft control during the maneuver by engaging the flight control system. Manual control may be regained at any time by simply exerting force on the control stick.

Figure 33 shows the HUD display three seconds prior to reaching the E/P (by any of the three control options). Note that the digital display on the lower right of the HUD is displaying time-to-go to the E/P during ingress only. Note also that the auto-flight mode has been selected and that the flight director cues are in the null position, indicating that the aircraft is on course. Because the E/P is offset with respect to the target, the target is out of the field-of-view of the HUD. The target designator, however, is limited to the field-of-view, and an imaginary line between the flight path marker (FPM) and the designator points in the direction of the target.

When the aircraft is one second from the E/P, the guidance issues a roll command to bank the aircraft in the direction of the target and with approximately the correct roll attitude for the anticipated delivery maneuver. This action is accompanied by a flashing FPM and the disappearance of the flight director cues. This action alerts the pilot that he has reached the E/P, that the ingress phase in completed, and that the delivery phase is about to begin.
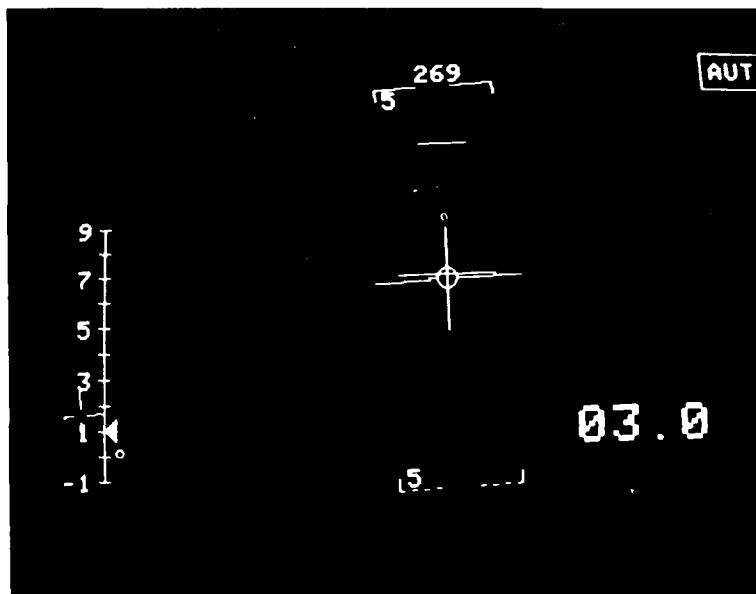
Figure 33. HUD - 3 Seconds to E/P

5.2.2 Delivery

The weapon delivery phase uses the guidance and control concepts developed under the Firefly II program, with some procedural changes implemented to better coordinate this phase with the ingress and egress phases. Figure 34 shows the HUD symbology for the delivery phase and Table 2 defines each symbol. In transitioning from the ingress phase to the delivery phase, two new symbols appear: the desired g's indicator and the roll authority box. In addition, the CCIP symbol becomes active and the digital display on the lower right (used for displaying time-to-go in the ingress mode) is used for ballistic range-at-release in thousands of feet.

The philosophy used in the IFTC/Firefly II integration design was to make the pilot's control task one of controlling the normal g loading on the aircraft using pitch control. Actual aircraft g's are displayed as is the pilot pre-selected value of delivery g's. These values are displayed on the g scale to allow the pilot to adjust the pitch control to match the "needles". The control philosophy, however, does not require precise agreement between selected and controlled g's because the Firefly II guidance controls the roll attitude of the aircraft to satisfy the turning plane vector relationship of equation 1.
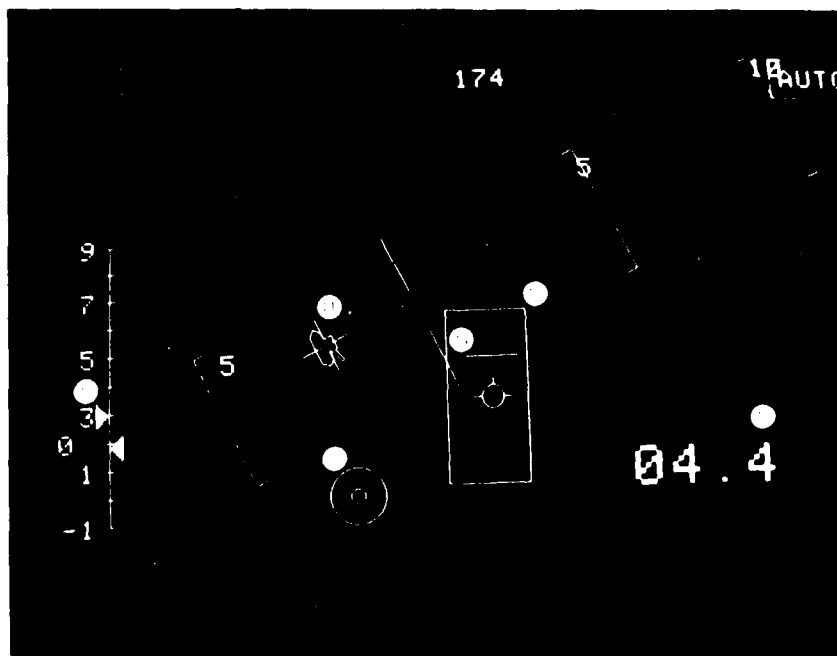
Figure 34. HUD Symbology, Delivery Phase

TABLE 2.   ADDITIONAL SYMBOLOGY FOR WEAPON DELIVERY

11.   Target Tracker (Shown over Simulated Target)
12.   Bomb Range @ Release
13.   Roll-Authority Steering Box
14.   Solution Cue
15.   Continuously Computed Impact Point (CCIP) Symbol
16.   Command G's

If the pilot uses pitch control to load the aircraft with approximately the pre-selected value of delivery g's, the delivery plane geometry will satisfy the specified minimum approach to target distance, with release range occurring at a somewhat larger value. Conversely, the pilot still has full freedom to control the aircraft in the standard Firefly II fashion of adjusting the g load and observing the HUD displayed value of release range until an acceptable value is attained. Maintaining that g load will then result in a constant turning rate and a steady value of release range.

The IFTC/Firefly II integration design has the advantage of allowing the pilot to pre-specify the delivery and egress g's and minimum penetration distance to the target, and his sole control task is one of controlling the g loading with the pitch stick. Roll control is fully automatic, and the pilot is not particularly concerned about monitoring release range, unless the actual g loading deviates significantly from the specified value. It is important to note that regardless of which scheme the pilot uses, he provides coarse inputs into the control system, while the automatic guidance provides the vernier control.

Figure 35 shows the HUD at the start of the weapon delivery phase. The aircraft has been banked automatically in the direction of the target and the flight director cues have been removed. Sufficient g loading has not yet been applied to the aircraft to allow the Firefly II guidance algorithm to find a steering solution. This situation is made apparent to the pilot by blanking the range-at-release display. This serves as a cue to the pilot to increase the g loading. For the situation shown in Figure 35, the pilot should be loading the aircraft with about 3 g's. Note that the CCIP symbol has been released from its stored position.

It should be emphasized that a 3-4 g delivery is not required for the guidance to converge on a solution. High g loading was required in this example because the pilot pre-selected 3 g's for the delivery maneuver and that value heavily influenced the computation of the E/P. If a lack of enemy defenses allows the pilot to make a lower rate turn on the target, the delivery g value may be manually changed to a lower value during ingress, and the flight computer will adjust the E/P position to reflect the
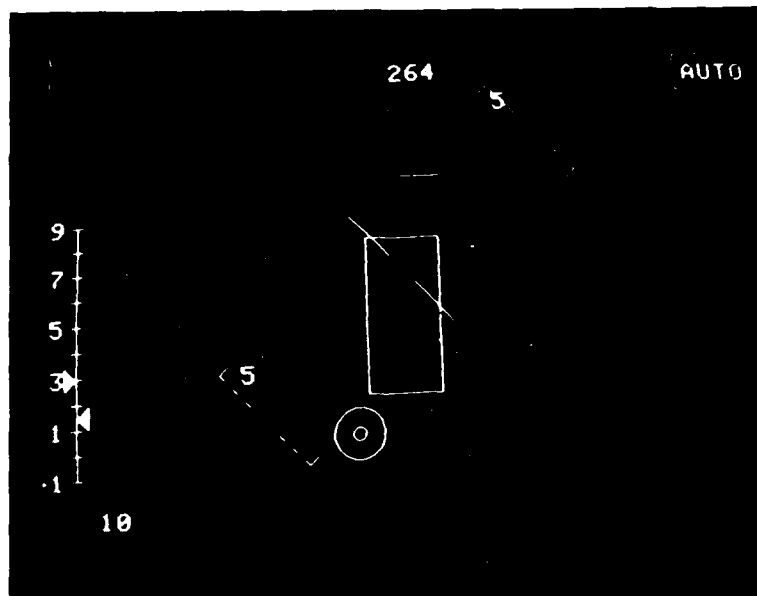
Figure 35.   Start of High-G Delivery - No Solution Yet

change.   Table 3 shows the E/P position and delivery plane inclina-
tion as a function of delivery g's.   Note that the release alti-
tude decreases even though the delivery plane inclination has
increased.   This is because the delivery turn radius has de-
creased, with a resulting decrease in delivery path length.

TABLE 3.   E/P POSITION AND DELIVERY PLANE INCLINATION
AS A FUNCTION OF DELIVERY G'S

G's	X_p	Y_p	Inclin-ation	Release Range	Release Altitude
2	12429	22652	5.3°	10324	1655
2.5	9332	19539	6.2°	10324	1504
3	7520	17716	6.8°	10324	1391
3.5	6315	16502	7.3°	10324	1303
4	5451	15630	7.7°	10324	1231

E/P Altitude	500'
TAS	480 kts
Min. Penetration Dist.	6000'
Angle-Off	90°

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It should also be noted that a "pop-up" type of delivery is not required if target defenses allow. In this case, the ingress may be made at a higher altitude and the resulting delivery maneuver may result in a delivery plane inclined negatively with respect to the horizon; that is, the aircraft will lose altitude during the maneuver. Table 4 shows the E/P position and delivery plan inclination with changing E/P altitude.

Figure 36 shows the situation just prior to weapon release. The target (tank) with its designator symbol is moving rapidly across the FOV of the HUD (from upper left to lower right) and the CCIP is about to pass through the target. Note that the ballistic range is 4400' and that the g loading is less than the specified 3 g's. This resulted in a closer penetration to the target than the specified value.

The roll authority box is centered about the FPM indicating that the roll guidance has enough roll rate authority for proper guidance control for the current level of g loading. As the CCIP passes through the target, the bomb is released and the delivery phase is completed.

TABLE 4.   E/P POSITION AND DELIVERY PLANE INCLINATION
AS A FUNCTION OF E/P ALTITUDE

E/P Alt	X_p	Y_p	Inclin- ation	Release Range	Release Altitude
500'	7520	17715	6.8°	10324	1391
750'	7482	17706	6.0°	10324	1534
1000'	7444	17692	5.2°	10324	1677
1500'	7369	17656	3.6°	10324	1964
2000'	7295	17606	2.0°	10324	2255
5000'	6868	17024	-8.0°	10324	4047

TAS   480 kts
Min. Penetration Dist.   6000'
Delivery G's   3
Angel-Off   90°

49
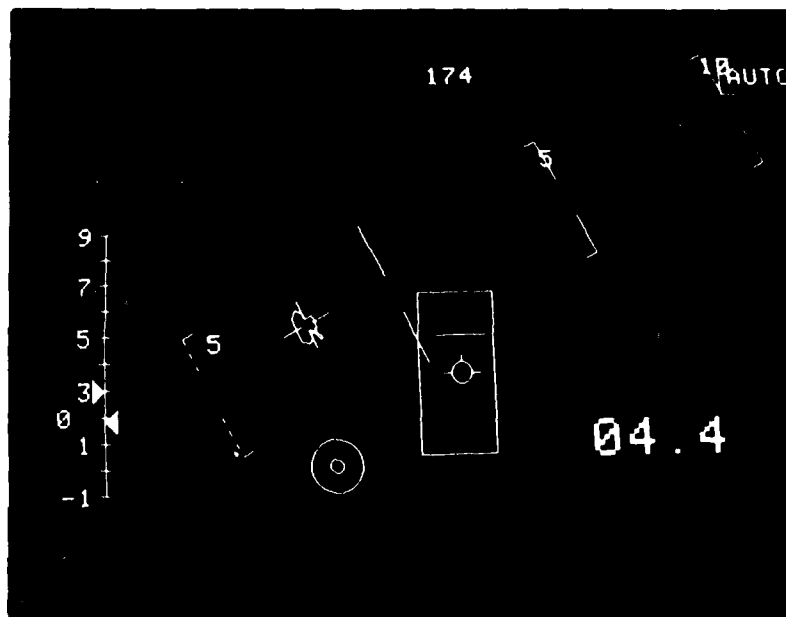
Figure 36. Just Prior to Weapon Release

Figures 37, 38, and 39 are simulation plots of the aircraft ground track with respect to the target as a function of a varying delivery parameter. Figure 37 plots the ground profile while varying the angle-off for 45°, 60°, and 90°. Note that for increasing angle-off values the E/P is offset a greater distance from the target. A larger angle-off allows more time from the start of the maneuver until release occurs, which may give more time for target acquisition or position refinement, but at the expense of gaining more altitude during the maneuver. Because of the increased offset, the maneuver may be somewhat more deceptive, particularly if ground terrain features are used to advantage. Note that release range remains essentially constant.

Figure 38 shows the ground track with respect to the target for varying minimum penetration-to-target distances. The angle-off was fixed at 60°. For this situation the net effect was to move the E/P with respect to the target to force the positioning of the delivery and egress trajectories to satisfy the penetration-to-target distance.

Figure 39 again shows the ground track with respect to the target, but with varying g loading during the delivery maneuver. As the specified g loading is increased, the E/P is moved closer to the target to account for the tighter turn radius. The release range

SCALE: 10000'/⊢————⊣

E/P ALT. - 700'
SPEED - 480 KTS
DELIV. G'S - 2½
EGRESS G'S - 3
MIN. DIST.
TO TARGET - 5000'
ANGLE-OFF - 45°, 60°, 90°
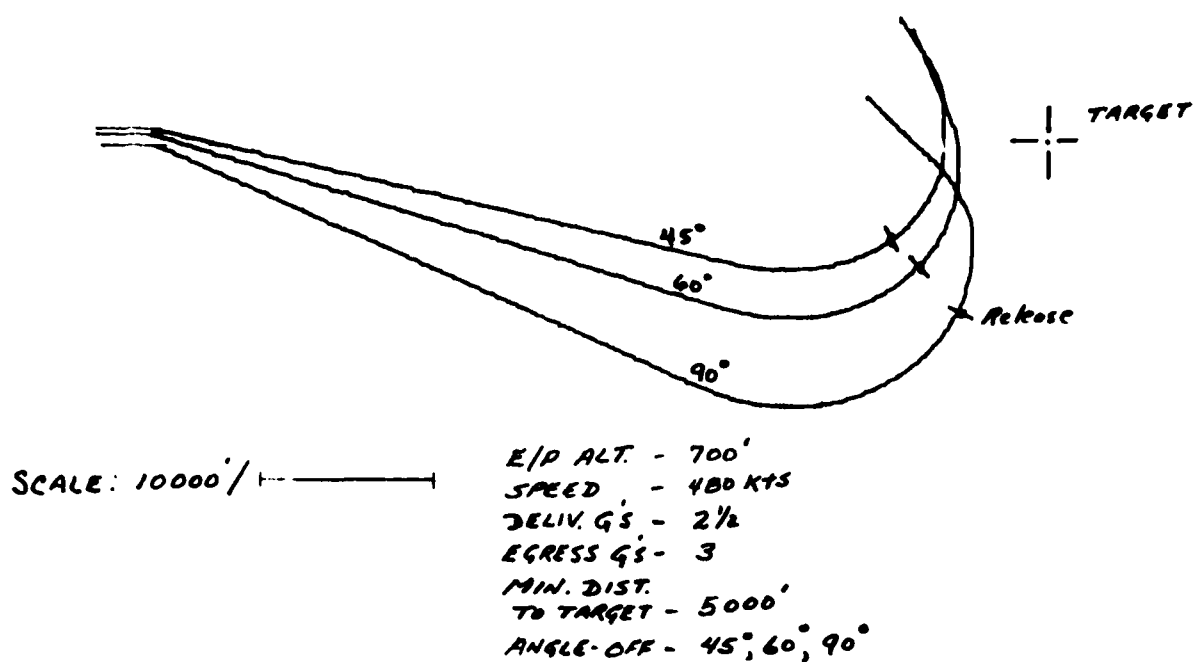
Figure 37.   Varying the Delivery Angle-Off

SCALE: 10000'/⊢————⊣

E/P ALT - 700'
SPEED - 480 KTS
DELIV. G'S - 2½
EGRESS G'S - 3
ANGLE-OFF - 60°
MIN. DIST.
TO TARGET- 3000'
6000'
9000'
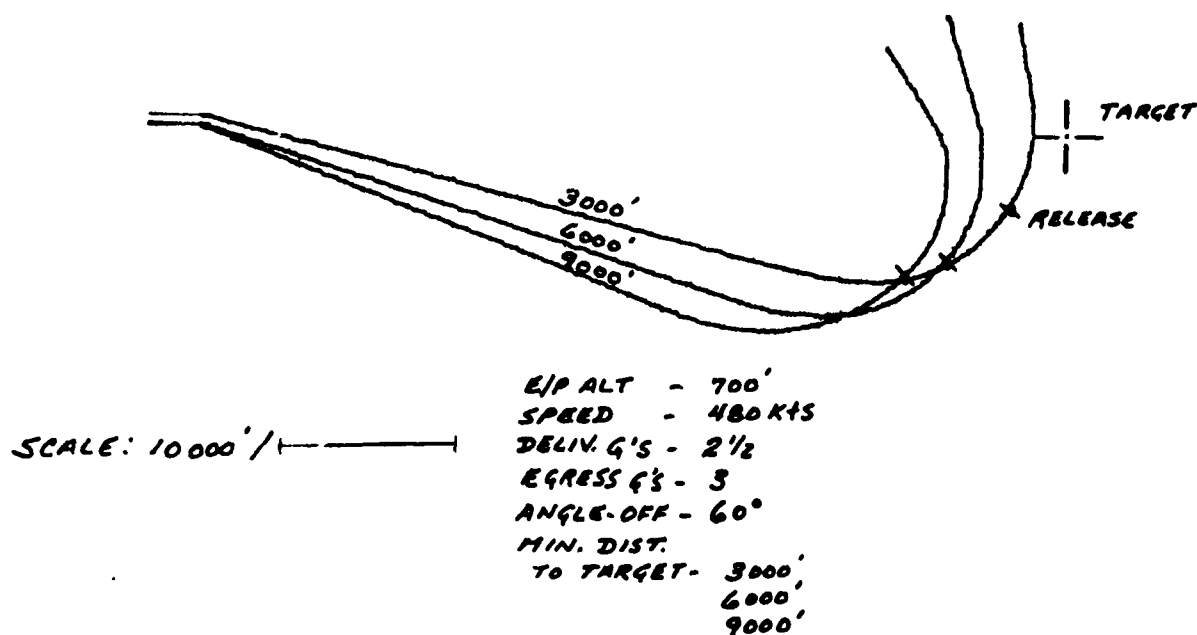
Figure 38.   Varying Penetration Distance

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SCALE: 10000'/⊢_____⌐   E/P ALT .   700'
                            SPEED .   480 KTS
                            MIN. DIST.
                             TO TARG. - 5000'
                            ANGLE-OFF.. 60°
                            DELIVERY G's 2,3 & 4
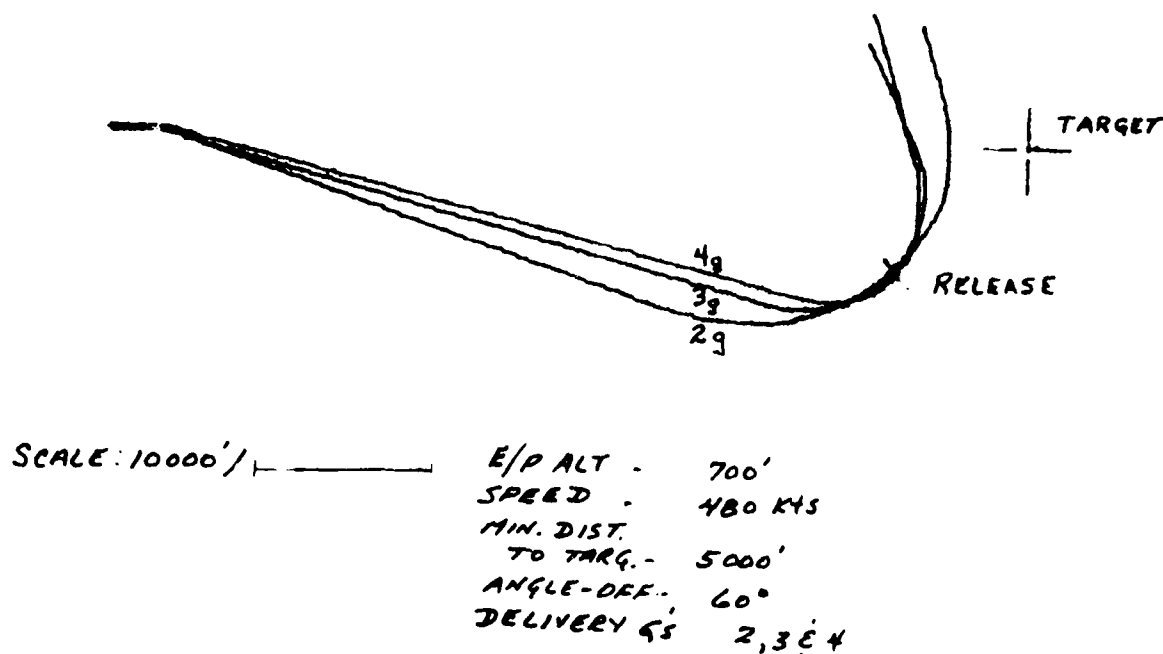
Figure 39. Varying Delivery G's

remains essentially constant, but the release altitude decreases slightly, even though the delivery plane inclination increases with increasing g's (see Table 3). This apparent paradox is explained by noting that the higher g loading results in a shorter turn radius and consequently a shorter path length from the start of the turn until release occurs (for the same angle-off). Even though the delivery plane increases in inclination as g's increase, the shorter flight time from start to release results in less altitude gain during the maneuver.

As can be seen from Figures 37, 38, and 39, changing the angle-off or the penetration-to-target distance has a bigger effect on the horizontal trajectory than does changing the delivery g loading.

5.2.3 Egress

The egress phase of the weapon delivery mission begins with the release of the last weapon to be dropped on the target.

Since a low level ingress to the target will result in a natural pop-up maneuver during the delivery, altitude will be gained. The twofold goal of this phase is to reduce the aircraft altitude and egress from the target area, accomplishing both as quickly as possible. The motivation, of course, is to avoid the target defenses.

The IFTC/Firefly II integration guidance results in a roll command of 120 degrees following weapon release. The pilot's control task remains one of maintaining g loading on the aircraft using manual pitch control, and this loading combined with the automatic roll control results in placing the components of the total aircraft lift vector in a downward direction and away from the target area. This action quickly reduces the altitude and maintains the same high-g turning maneuver initiated by the delivery phase.

The 120° roll maneuver is commanded only if the altitude is above 1000' at release time. If not, the roll command is limited to 90°. The 120° roll attitude is maintained until either the pitch angle reaches -10°, or until the pull-up discrete is set. The pull-up discrete is set as a function of the ground closing rate and a pilot-selectable ground clearance distance, assuming a 3-4 g pull-up. When either of these criteria is satisfied, the roll command is changed to 0° to cause a rollout of the inverted flight. The pilot maintains g's until the pull-up is completed and level flight is re-established. Figure 40 shows the HUD during a 90° roll egress.

The turning maneuver away from the target continues until the relative bearing to target exceeds ± 120 degrees. At that time the egress phase is completed and the IFTC navigation mode assumes
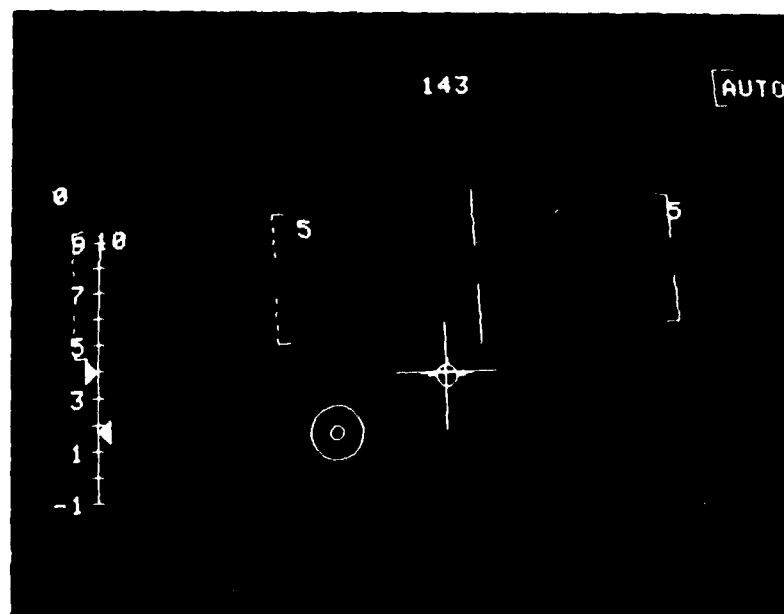
Figure 40.   Egress - 90° Roll

control of the aircraft. The trajectory generator computes a
"capture" trajectory to transition the aircraft back to the nomi-
nal flight plan, and the speed and time schedule is recomputed.

5.2.4 Re-Attack

    If a re-attack on the target is required, the procedure is
to simply select the CCIP weapon delivery mode, use the weapons
panel to designate which target is to be attacked, and engage the
flight control system. The IFTC/Firefly II guidance will select
the designated target coordinates and compute the E/P position
based on the current target/aircraft geometry. The guidance will
place the aircraft in a 2-g turn to acquire the proper track to
the E/P. The pilot can arbitrarily select the re-attack heading
by flying the aircraft to appropriately position it with respect
to the target, prior to re-engaging the CCIP weapon delivery mode.
Figure 41 shows the HUD during a 2-g re-attack maneuver to re-
acquire the target.
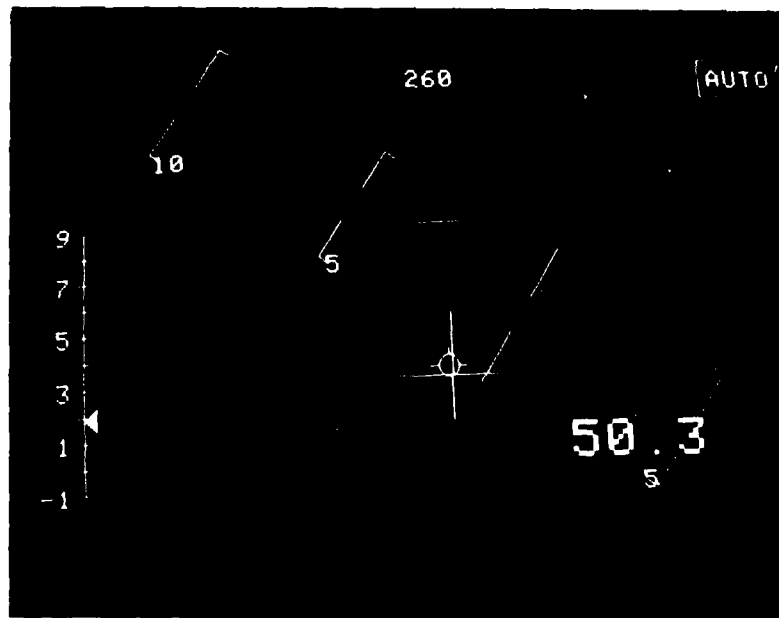
Figure 41. 2-G Re-Attack Maneuver

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6   PILOT TESTING

6.1 PURPOSE

The purpose of pilot testing on the IFTC system simulation was to expose the IFTC concept, the Mission Data Transfer System, the projected/electronic map display (EPMD), and the IFTC/Firefly II weapon delivery integration to operational pilots. There were four subject pilots used during the testing period. The subjects were trained -- two at at time -- to operate the system by a combination of in-the-classroom and in-the-cockpit instruction including instruction for using the Mission Data Transfer System. The IFTC movie [6] was used to provide an introduction to the IFTC concept. The movie was followed by a short 35-mm slide presentation of a multiple aircraft strike mission which was used to emphasize the improvement in aircraft exchange ratio (loss of friendly/loss enemy) that could be gained by providing close time control among the aircraft of the strike force for three phases of mission: FEBA crossing during ingress, coordinated air-to-ground weapon delivery, and FEBA crossing during egress.

An overview of the program and a statement of the pilot testing objectives was given following the slide presentation. It was emphasized that careful thought should be given to all questionaire responses because this was an opportunity for operational pilots to have some significant inputs to the design of future military flight management systems.

A walk-through of the LSI Hybrid Simulation Laboratory followed the program overview. Classroom training was given for the operational procedures for the cockpit Status Display, the Keyboard, and the Tactical Situation Display (TSD or EPMD) and mode controller. This training was followed by a brief introduction to the Mission Data Transfer System (MDTS).

The pilots were taken to the simulator laboratory for more intensive MDTS training, and were then alternated between the cockpit (Figure 42) for familiarization flight and the MDTS for hands-on operation.

The second day of training started with a classroom explanation of the IFTC/Firefly II integration, which was presented from the pilot's perspective. Each phase of the weapon delivery -- ingress, delivery, and egress -- was examined in terms of what the pilot was expected to do, what the automatic control system was doing to the aircraft, and what symbology was active on the HUD. Overhead viewgraphs were used to show the HUD symbology, and ground track profiles for typical weapon delivery maneuvers. After classroom instruction, several short weapon delivery profiles were flown in the simulator by the instructor and observed by the pilots.
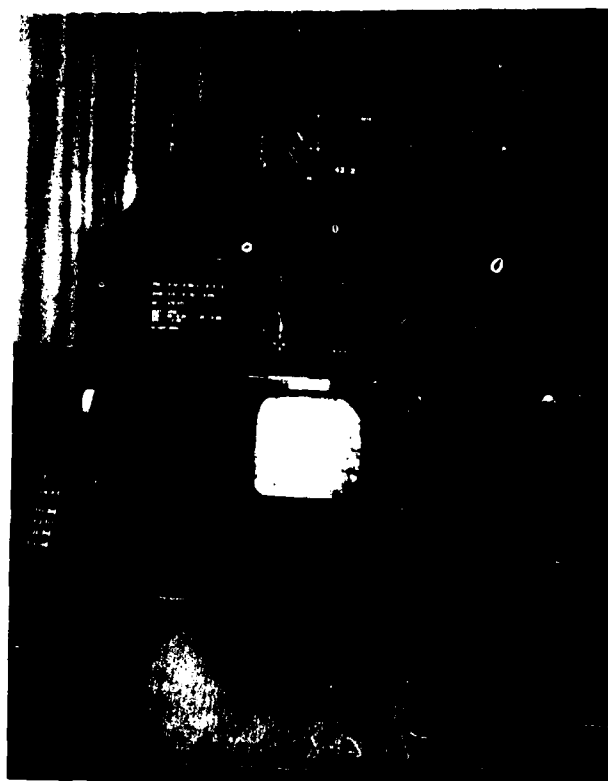
Figure 42.   IFTC Cockpit Simulator

Following the weapon delivery demonstration by the instructor, the pilots were alternately allowed to fly the missions until they felt comfortable with the technique and had gained some proficiency with the system.   Generally, this required 1-to-2 hours for each pilot.

The pilots were then briefed for the training mission which contained all the elements and activities of the primary or testing mission.   Included were enroute navigation, FEBA crossing, time-coordination, threat avoidance, weapon delivery, egress and return to base.   After the weapon delivery maneuver, the primary mission was interrupted by a mission redirect.   Both pilots flew the training mission at least twice.

The third day consisted of briefing both pilots on the testing mission shown in Figure 43.   Following the briefing the pilots alternately flew the mission.   The instructor served as the forward area controller for vocal contacts with the pilot and also initiated any simulated data-link activity.

Following the successful completion of the mission, each pilot was given the post-flight questionnaire.
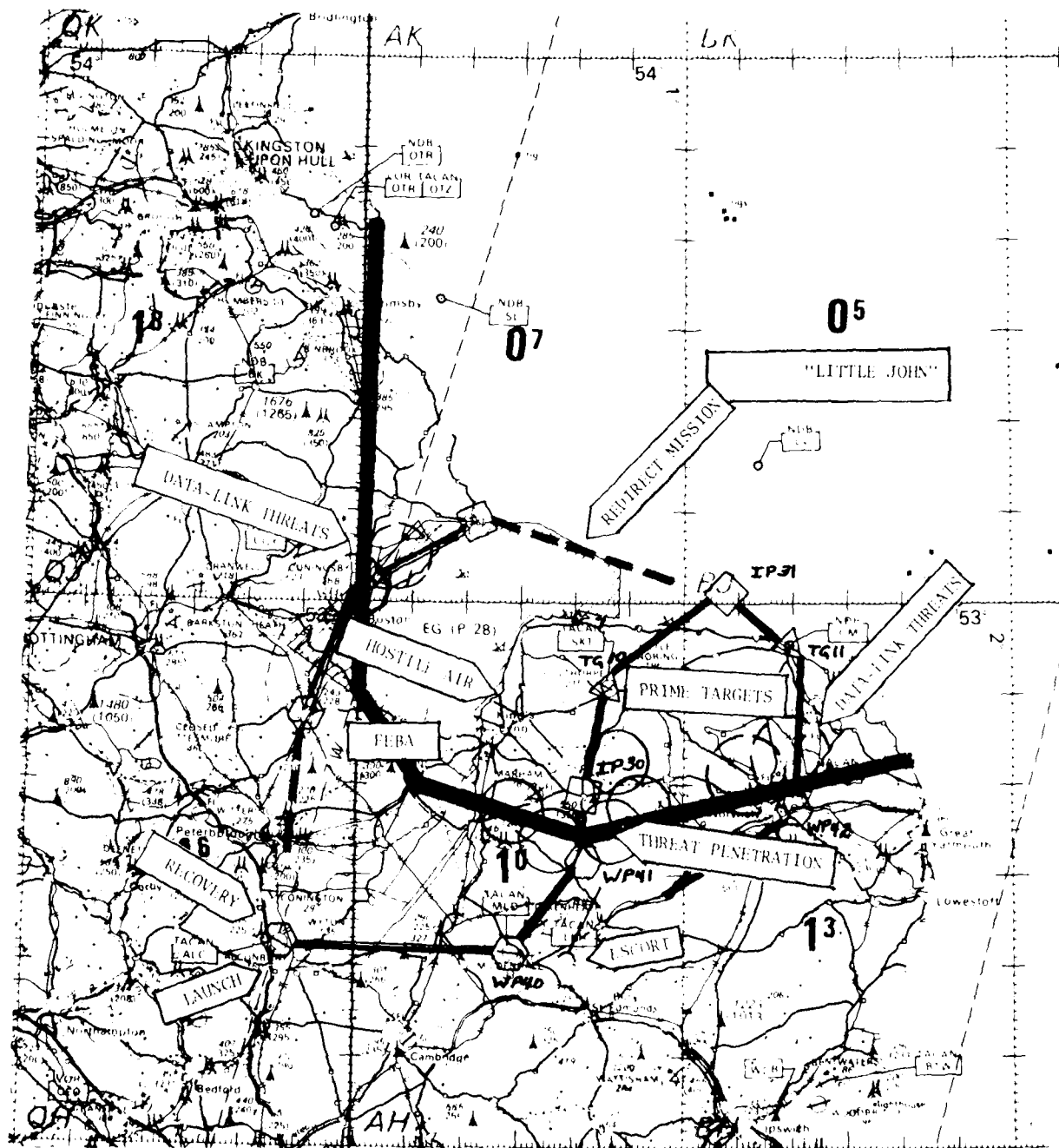
Figure 43. Testing Scenario

Time for debriefing was provided at the end of each pilot testing session to allow the pilots a forum for comments, complaints, likes, dislikes, and overall re-action to the system.

6.2 TESTING HYPOTHESES, STATEMENTS, AND TESTING INFLUENCE

The questionnaire and debriefing material was used to prove or disprove the following testing hypotheses.

Tactical Situation Display Requirements

Hypothesis: A projected moving map display provides necessary, head-down tactical awareness capability for pilot orientation with respect to navigation, in-flight mission redirects, target identification, and threat avoidance in an advanced tactical aircraft.

Testing Influence

Mission Scenario -

- Data link new threats (ground and air) for display
- Display horizontal and vertical profiles

Subject Selection Criteria -

- Previous map display experience (A-7D or E, F-111)

Data Acquisition -

- Questionnaire - (likes, dislikes, information used, scaling, look-ahead capability, vertical situation, usefulness during TA/TF)

DTM Operational Concept Integration

Hypothesis: Pilot portable mission loading/mission recording increases the pilot/aircraft mission readiness, flexibility, and reporting accuracy when used with advanced digital navigation weapon delivery systems.

Testing Influence

Mission Scenario -

- Utilize DTM for mission loading
- Simulate using DTM for mission data recording
- Discuss the workload without DTM

Subject Selection Criteria -

- Area-Nav/Digital Weapon Delivery experience (F-111)

Data Acquisition -

- Questionnaire (likes, dislikes, other uses)

IFTC/Firefly II Integration

Hypothesis: A capability for on-board trajectory generation increases the probability of mission (A/G) success by providing ingress path control (manual or automatic steering), while allowing jinking, to a dynamically changing offset point during ingress maneuvers. Ingress and egress maneuvers are tailored to reduce the pilot's exposure to ground-based threats.

Testing Influence

Mission Scenario -

- Jinking/non-jinking (threat interference)
- HUD alert cues for jinking break-off
- Flight director cues on HUD
- Manual/automatic egress steering
- Re-attack on target

Subject Selection Criteria -

- Advanced digital avionics system experience
- Capable of grasping new concepts

Data Acquisition -

- Questionnaire

6.3 METHOD OF TESTING

The LSI Hybrid Computing Facility was used to perform real-time, man-in-the-loop simulation of the IFTC system. The DTM, EPMD, and Firefly II weapon delivery algorithms were incorporated in the simulator. The Mission Data Transfer System, of which the DTM is a part, was installed in the Hybrid Computing Lab and, together with navigation planning maps, was used for mission planning and DTM loading.

Air Force pilots were used as test subjects. Sufficient pilot training was provided to familiarize the test subjects with the system. Both briefings and in-the-simulator flying was used for training.

6.4 TESTING SCENARIO

6.4.1 General

The pilot testing scenario is shown in Figure 43 and contains the basic elements of a typical fighter mission:

- Launch
- Rendezvous with escort a/c (time coordinated)
- Penetration of FEBA at low level
- Maneuvering through SAM enevelopes
- Interdiction by hostile air
- Air-to-ground weapon delivery (2 targets, planned)
- Encounter with SAMs previously unknown to intelligence
- Egress across the FEBA
- Recovery

While executing the planned mission, an interruption occurred in the form of a mission redirect. This redirect consisted of a new target IP, target, egress point, and recovery base. During the execution of the redirect, SAMs were activated near the target and FEBA.

6.4.2 Mission Planning

The pilot was briefed on the details of the primary mission. He was then required to enter the coordinates and other pertinent information into the Mission Data Transfer System. The cruise nav points (WP40 and WP42) were previously entered into the system data base. The pilot needed only to pull them from the data base by using the proper identifiers. The data for the target IPs (IP30, IP31) and targets (TG10, TG11) were determined from the planning map and manually entered into the planning system.

Likewise, the ground threat information (λ, ℓ, lethal radius) was partially available through Intelligence and previously loaded as a part of the system data base, but a few new threats were left for the pilot to enter.

Following data insertion and inspection, the pilot used the system to form the flight plan. The data module was loaded with the flight plan and ground threat data.

6.4.3 Mission Execution

To execute the mission, the pilot carried the module to the cockpit and inserted it into the DTM receptacle. The simulation computer read the DTM data and transferred this data to the simulation computer flight data library. The cockpit displays were activated with the mission data.

The mission was located in England because three-map scale coverage was available in the Ferranti EPMD only for that area. The launch occurred from Alconbury, an operational NATO base. The first enroute nav point was Mildenhall where the rendezvous with the escort aircraft occurred. The escort aircraft appeared on the TSD (electronically generated) and accompanied the IFTC aircraft to the FEBA and IP30. The FEBA also appeared on the TSD as a dashed line. (This would normally be a part of the DTM data, updated daily or hourly by intelligence and loaded into the planning system data base.)

As the pilot approached the FEBA, generally he manually deviated slightly from the flight path to cause a modified trajectory segment (A/C to IP30) to be drawn through the threat enevelope intersection, for minimum exposure.

An arrival time (TOA) was specified at IP30 to ensure time coordinated crossing of the FEBA. As the A/C approached IP30, two airborne bandits appeared at about the 10 o'clock position at 500 feet altitude. The pilot optionally performed evasive action at this time, staying low and keeping his nose pointed at the bandits. The bandits did not detect his presence and approximately 1.0 minute later he resumed his attack on TG10, but at a different-than-planned heading.

CCIP (continuously computed impact point) visual weapon delivery mode was selected and guidance was followed to position the aircraft at the proper offset point to start the Firefly II weapon delivery. The position of this offset point was adjusted by the IFTC trajectory algorithm to properly account for the unplanned evasive action.

The pilot had previously elected to start the weapon delivery maneuver at an AGL of 500' - 1000'. The minimum penetration to the target had been selected as 6000'. He elected to pull 3 g's during the delivery and 4 g's during the escape maneuver. His maximum altitude attained during the delivery has been selected as 1500' AGL, and the angle-off specified at 45 degrees.

Automatic roll and pitch steering generally was selected for control to the offset point; however, HUD flight director cues were provided for manual steering. In the manual mode the pilot could elect to jink, and HUD cues warned him when to break off the jinking and follow the steering cues to ensure that the A/C arrived at the offset point to properly start the weapon delivery maneuver.

The pilot performed the weapon delivery maneuver, in a slightly climbing, high-g turn. The pilot used only pitch control to provide the desired level of g's. Roll steering was coupled automatically to the authority limits provided by the Firefly II guidance algorithms.

Weapon release occurred automatically at the proper point in the maneuver. After detection of weapon release, the IFTC roll guidance maneuvered the A/C to a 120°, slightly inverted, roll attitude (if the altitude exceeded 1000'). The pilot continued to fly pitch only, maintaining the desired level of normal g's. This inverted maneuver was necessary to quickly reduce the A/C altitude, and thereby reduce exposure.

When the Firefly II pull-up algorithm set the pull-up discrete, the roll autopilot commanded a roll-out to 0°. The pilot's task continued to be one of maintaining normal g's by using pitch stick input. This resulted in a smooth pull-up at the minimum altitude level specified by the pilot. Following weapon delivery and egress, the mission continued to the second target and IP (IP31 and TG11).

Just prior to approaching IP31, the pilot was notified via the displays that he had just been given a mission redirect. The second weapon delivery maneuver was aborted and the TSD and Status Display were used to examine the redirect mission for position and type. He also used the displays to determine his estimated fuel reserves at the recovery base for the redirect mission.

Since satisfactory fuel reserves were available, the pilot chose to comply with the redirect. The redirect profile was drawn on the TSD by the mission computer following notification and data for the redirect, assumed to have come via a secure data-link system (JTIDS-like).

To engage the flight controls to the redirect profile, the pilot simply depressed the ENGAGE button while in the NAV mode select position.

The redirect mission was flown resulting in A/G weapon delivery at the redirect target. Two SAMs were activated at the target/FEBA area as the target was approached. Egress to the recovery area followed weapon delivery, but actual recovery (landing) was not simulated.

6.5   PILOT TESTING RESULTS

Table 5 summarizes the duties, education, and aircraft system experience for each pilot involved in the testing. As is evident from the table, three of the four pilots had experience with flight directors, HUDs, area nav systems, digital weapon delivery systems, and data entry keyboards. Two of the pilots also had experience with moving map displays. The test subject's aircraft and systems experience provided a good base from which to evaluate the IFTC system.

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TABLE 5.   SUMMARY OF TEST SUBJECTS AND EXPERIENCE

SUBJECT/ DUTIES/ EDUCATION	FLIGHT EXPERIENCE (HOURS)	HAS SUBJECT HAD FLIGHT EXPERIENCE WITH THESE SYSTEMS? (HOURS)					
		FLT DIRECTOR	MOVING MAP DISPLAY	HUD	AREA NAV SYSTEM	DIGITAL W/D SYSTEM	KEYBOARD DATA-LOAD SYSTEM *
#1 - Liaison between TAC Dir. of Requirements and ASD; Flt. Safety Trng; B.S., Physical Sci.	CF39A, F-111D (1500 hrs), F-4	YES (1500)	YES (1500)	YES (1500)	YES (1500)	YES	YES
#2 - Liaison between TAC and ASD; Maint. School; BSIE; FAC - WILD WEASEL	CT-39A F-4 (3000 hrs)	YES (3000)	NO	NO	NO	NO	NO
#3 - Engineer, AFAL; Sqdn. Pilot, Ohio Nat'l Guard; BSEE	F-100D, A7-D (260 hrs)	YES (260)	YES (260)	YES (260)	YES (260)	YES (260)	YES
#4 - Operational test pilot - F-16 Combined Test Force; B.S. Engr Sci.	F-16/YF-16/ YF-17/F-15/ F-4/F-104/ F-100/F-105/ T-37/T-33/ T-38/T-39	YES (350)	NO	YES (300)	YES (3000)	YES (300)	YES

* any system requiring extensive data entry from a cockpit keyboard (area nav, ins)

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The post-flight questionnaire probed for pilot opinions in seven areas:

- Trajectory/TOA Control
- Data Transfer System
- Data Transfer System enhancements
- EPMD
- VSD
- Weapon delivery
- General observations/reactions

Each area will be summarized separately in the following paragraphs.

6.5.1 Trajectory/TOA Control

The pilots were queried to determine if they felt that the training and testing were sufficient to give them an adequate understanding of trajectory and time control. The concensus was that the training and testing were adequate and each pilot understood what the IFTC system was doing with the TOA and airspeed constraints in addition to computing the three-dimensional trajectory. The pilots were asked to rank accurate TOA/TOT control, vertical profile tracking, horizontal path tracking, and mission recovery after maneuvers in order of importance. Accurate TOA/TOT was the unanimous choice, especially for nuclear delivery and multiple aircraft strike missions. The remaining three were given about equal ranking, with the comment that all are important with relative importance being very much a function of mission type, time of day, and weather conditions. Opinions were given that racetrack holding, close air support (CAS) contact point maintenance, and MIG CAP support would all benefit from trajectory-time control.

The current simulation limits A/C bank angles to 45 degrees. It was felt by the pilots that bank angle limits should be opened up to 60 degrees to allow greater maneuvering ability (smaller turn radii), especially in high-threat areas. The pilots also appreciated the fact that the trajectory generator created the most direct path to the next turn point in the mission rather than steering back to the planned track following mission deviations.

Other comments indicated that IFTC should reduce pilot workload and increase survivability, and should be especially useful in high workload situations. It was felt that the real-time trajectory computations and readjustment of the time/speed profile following an interruption to the planned mission would greatly increase operational capability. It was emphasized by the pilots that any heads-down activity associated with using the system must be minimized, especially in hostile areas. This would imply that button-pushing activity while on the hostile side of the FEBA must be minimal. It would be necessary to change flight plans either

by transfer loading of alternate mission data from the DTM to flight computer, or by data-linking new mission data to the cockpit and using an IFTC-like system to automatically process and display the new flight profile complete with ETA's, fuel, and distance data.

6.5.2 Data Transfer System

Current nav planning techniques consume from 70% - 90% of the total mission planning time. It was the unanimous opinion of all pilot test subjects that this respresents a disproportionate amount of time, and that they would rather have more time for mission tactics planning. It was their opinion that the mission data transfer system (MDTS) provided a great step toward providing the shift from time spent in mission planning to tactics planning. Several suggestions for improvement were made, however, which the pilots felt would be necessary to provide the needed capability.

- The MDTS system should provide fuel use estimates, ETAs, and distance computations for each flight leg. Without the automatic computation of these quantities, the pilot is still forced to determine them manually -- a time consuming effort. The performance data from the T.O. 1F-XX-1 Flight Manual could be stored in the MDTS data base and used to compute the needed values. The pilot would enter into the MDTS the expected stores and rack positions and whether or not external fuel pods would be used. The pilot would be queried for any other required information via the MDTS interactive display.

- The MDTS printout should be compatible with (if not identical to) the standard Air Force mission planning form, AF FORM 70. This form is the format with which the pilot is acquainted and would like to see as the final output of the MDTS. The flight plan should be displayed on the MDTS CRT in the same FORM 70 format.

- The MDTS ground system should be very simple and logical to use. The self-help instructions provided by the MDTS were felt to be useful, but need to be improved.

- The ability of the DTM to accept in-flight data was felt to be of use, especially for improvement of post-flight debriefing accuracy. Some capability is required, however, to allow the pilot some quick and convenient means of annotating the data, preferrably while maintaining a heads-up posture. In most cases, the annotation could consist of 1 to 4 words (tank, quad-twenty-three, etc.) to adequately describe a target of opportunity, for example. The coordinates of the object would be determined and transmitted automatically via the data bus to the DTM by whatever sensor tracker was used to designate the object.

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The problem of conveniently annotating the data could be solved by using a voice controlled input device (voice recognition system). The pilot would simply designate the target using the tracker and utter some appropriate word or words to identify it. The voice recognition system would cause a single, multi-bit code to be stored in the DTM for debriefing identification use.

● The pilot must have a rapid procedure for verifying the transfer of the DTM data to the cockpit computer.

Overall the pilot's feelings toward the MDTS were those of considering it an absolute necessity for loading the flight computer with the data-base required by an IFTC-like system. With it, mission reaction time should be greatly reduced. When asked if most pilots would trust the flight plan creation and module loading to others, each indicated that he would as long as some means existed for rapidly checking the data. The subjects indicated the necessity for the pilot's familiarity with the sytem, however, since last-minute mission changes would have to be made by the pilot.

It was also felt that displaying the data on the MDTS CRT terminals in the same format as it would appear in the cockpit, may not be beneficial -- displaying it in FORM 70 format is more important. In essence, what the pilots are looking for in the ground equipment is a Computer-Aided Mission Planning System (CAMPS) capability, coupled with the power and flexibility afforded by the IFTC system.

6.5.3 DTM System Enhancement

The pilots were asked to make suggestions for enhancing the capability of the MDTS system. All indicated the desireability for some method of rapidly entering nav point-target point position data into the ground system. In their opinion, probably the best technique for accomplishing this would be to implement an X-Y digitizer consisting of a display board and some means of electronically designating a position on the board. Either a hardcopy tactical planning map could be attached to the digitizer table, or the tactical map image could be projected to the back of a transluscent digitizer, perhaps using the same filmstrip as used for the EPMD. A hand-held key pad could be used for entering elevation data, TOA, course, airspeeds, or any other required data. Symbolically labelled keys would be used to enter waypoint type (△, □ -).

It was also suggested that a "stick-map" displayed on the MDTS CRT display would be useful. This would verify to the pilot that his mission points had been accurately entered and positioned in the flight plan in the proper order.

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6.5.4 Electronic Projected Map Display

All pilots were enthusiastic about the EPMD. Two of the four had extensive experience with map displays in the A-7D and F-111D, and were well aware of the operational advantages. Neither the A-7D or F-111D maps have the capability of displaying electronic imagery with the projected map.

Navigation system accuracy monitoring and ground track monitoring have been the traditional uses of cockpit map displays, but with the addition of electronic imagery, many additional capabilities become possible. The IFTC system employed a graphics processor to allow the electronic display of the nav and weapon delivery points, the curvi-linear trajectory between the points, ground and airborne threat symbols, friendly aircraft symbols, and alpha-numeric data. In the pilots' opinion the addition of the graphics information was extremely useful. In addition to the overall pilot orientation usefulness of displaying the flight plan, the capture profile for returning to the mission track following deviations was well received. The TOA error displayed on the EPMD informed the pilot as to how early or late he would be with respect to the assigned TOA.

The pilots were also enthusiastic about the display of the ground threat footprint for tactical awareness, and for the possibility it allows for manual steering through dense threat areas. It was also felt that the display of ground threats and the ground track profile for the maneuvering weapon delivery trajectory (ingress-delivery-egress) would greatly improve pilot orientation.

Several recommendations were made by the pilots for making the EPMD more useful:

- Map scaling should have one more selection at each end, i.e., smaller than 18 nm (top-to-bottom) is needed for weapon delivery and larger than 72 nm is needed for high-altitude radar correlation.

- Map should provide the option of displaying some data which is currently buried in the paging structure of the Status Display, i.e., depressing an EPMD mode button labeled FUEL or ETA would result in fuel estim. or times-of-arrival to be displayed near each nav poin

- The EPMD could be used to provide weapon status information. This would involve driving the projected map to a blank frame and displaying graphically a top-view of the aircraft. Each bomb rack, bomb, sensor pod, external fuel tank and missile would be shown at its proper location and the status of each could be indicated (armed, on, half-full, etc.).

- It was felt that the north-up display mode was of limited value, perhaps useful for general orientation only.

- The X-hair designator should operate in the track-up, moving map mode. This means that the X-hair must be motion stabilized to eliminate drift in the absence of slewing inputs.

- If terrain information were available, terrain masking areas could be presented on the EPMD as a function of altitude and defense positions.

It was felt that the map display size (5 in. x 5 in.) was adequate, and the graphics symbology was generally visible. There was some concern that the map field-of-view (FOV) might be too limited, but evaluation of the FOV is not possible without cockpit motion. The consensus of the pilots was that some sort of map display capability is essential for tactical awareness in a high workload, heavily defended environment.

6.5.5 Vertical Situation Display (VSD)

No changes had been made to the vertical display format from the previous contract. By depressing the VSD key on the EPMD mode controller, the pilot was able to display the altitude schedule for the next 80 nm of along-track distance (see Figure 11). The general feeling was that a VSD is not needed for VFR flight conditions, and would need to be greatly improved for IFR use. The following specific comments were made:

- The display must show terrain information

- TA/TF radar return data should be displayed

- The VSD should include vertical information about airborne and ground-based threats

6.5.6 Weapon Delivery

The IFTC/Firefly II weapon delivery integration allows an air-to-ground delivery of bombs while pulling g's, resulting in a curved delivery profile. The delivery profile, as a result, is offset with respect to the target, eliminating many of the risks associated with target fly-over.

The general comments from the pilots -- after being briefly trained to understand and fly the technique -- were that the concept of offset bombing while pulling g's seemed viable. The advantages are escape from fragmentation effects, increased difficulty of tracking by the defenses, and no requirement for

overflight of the target. The disadvantages are the increased difficulty of target designation, and some possibility of disorientation while maneuvering at night or in weather. The simulation was not able to duplicate either the target designation task or the non-visual conditions.

The HUD symbology was changed between the first two pilot subjects and the last two. The initial HUD mechanization displayed a horizon line and a somewhat unconventional roll flight director. The first two pilots had difficulty using the flight director and, in addition, pitch attitude information was lost whenever the horizon line moved off the HUD FOV. Both pilots indicated a strong desire for implementing a pitch flight director, also.

For these reasons the HUD symbology was changed to add a pitch ladder (horizon, $\pm$ 5 deg, $\pm$ 10 deg, $\pm$ 15 deg) and a conventional set of pitch-roll flight director bars. The symbology and scaling were made consistent with the F-16 production HUD. These changes greatly increased the learning rate for the second set of pilots, and they were very quickly able to perform consistent weapon delivery maneuvers.

Generally, the pilots felt that fully-coupled roll and pitch autopilot control for steering to the offset point (ingress) was desireable, as long as immediate, manual over-ride was possible. Jinking during ingress is also a required capability. The pilot training time available did not allow sufficient practice of jinking maneuvers during ingress, and as a result the pilots could not evaluate the HUD cues used for the jinking break-off warning.

The pilot-specified parameters for the delivery (delivery g's, egress g's, penetration distance, offset point altitude, and angle-off) were judged to be sufficient to offer delivery flexibility. It was suggested that other parameters the pilot may want to specify would include ground clearance (following pull-up on egress), rate-of-descent during egress, and aircraft heading into and out of the target area to take advantage of terrain masking. Some pilots indicated the desireability of being able to determine (presumably from a cockpit display) the effects of varying these parameters on the ballistic range and bombing accuracy.

The training of the last two pilots included varying the delivery parameters of delivery g's and angle-off to give the pilots a feel for the effects. X-Y plots of the ingress-delivery-egress were made for each practice run.

Pulling g's while in semi-inverted flight and at low level was uncomfortable to the pilot , initially, but sufficient practice reinforced the control concept of maintaining g loading during the egress pull-down and roll-out. The pilots' first reaction was to

relax the g loading during pull-down at a time when the g loading vector was being rotated by commands to the roll autopilot to effect the pull-up to level flight. Once the pilots understood the control actions, the necessity of maintaining g loading, and practiced the maneuver until it became comfortable, then the control philosophy became acceptable.

The pilots, however, tended to favor a manual roll control rather than automatic, presumably using a HUD presented roll flight director. This was not a unanimous opinion, however. A manual egress mode was not mechanized so no simulation experience was possible. As a result of pilot feedback, the roll angle in egress was reduced from 120 degrees to 90 degrees if the release altitude was below 1000 feet. This limiting prevented high-g pull-down at altitudes below 1000 feet.

6.5.7 General Observations

The pilots were given the opportunity to make comments relating to three general areas. Their comments are listed, but it should be noted that these comments are a collection from the four pilot subjects and did not always represent the consensus.

- What phases/maneuvers should be A/P coupled?

  "All, if TA/TF is included in the system"
  "W/D with A/P override at all times"
  "Could function as a purely flight directive system"
  "Enroute, ingress of W/D, and profile recapture after W/D"

- What new features were demonstrated and liked?

  "Flight path predictions on moving map (including turn radii)"
  "Inverted, low altitude recovery with roll-coupled A/P"
  "Autothrottle"
  "DTM system"
  "Integrated map and HSD"

- What improvements would you make?

  "Open bank-angle limits from 45 deg to 60 deg, particularly in the tactical area"
  "Implement simple A/P modes of heading hold/select, attitude hold/select, and TAS hold/select"
  "Eliminate the W/D roll-authority box on HUD"
  "X-hair should be usable in track-up mode"
  "Eliminate the g scale (on HUD) and move the box (roll authority) vertically for g control"
  "Add radar to the EPMD display"

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7.1 GENERAL DESCRIPTION

The IFTC simulation was developed under the previous contract to demonstrate the IFTC concept, and was modified to add the capability of the Development Program. The simulation equipment includes a PDP-11/70 main-frame digital computer with its associated disc memory storage devices and tape drives, configured to interface with an Applied Dynamics Model AD-4 Hybrid Computer. Also included were two mini-computers (a PDP-11/20 and 11/03), a Ramtek RM9400 color graphics generator, and a single-seat tactical cockpit simulator with its associated side-stick controller, autothrottle, CRT displays, keyboards, Ferranti EPMD, LSI Data Transfer Module and receptacle, HUD simulator, and various other analog and digital displays. The cockpit was connected to the PDP-11/70 and the AD-4 via analog and digital interface lines.

Figure 44 shows the complete LSI Simulation/Analysis Test Facility including capability which was not required for the IFTC program.

7.2 SIMULATION CONFIGURATION

Figure 45 shows the broad organization of the simulation with respect to the computing and control elements. The majority of the simulation programming was performed in FORTRAN IV-PLUS and compiled and executed in the PDP-11/70 using the RSX-11M-V3.2 operating system. In particular, the control/display management, four-dimensional trajectory generation, navigation guidance, weapon delivery and ingress/egress guidance, and the HUD display symbology computations were performed by the 11/70.

The aircraft dynamics model was divided between the 11/70 and the AD-4. The differential equations to mechanize the six-degree-of-freedom stability axes model were implemented in analog fashion on the AD-4. The aero coefficients as functions of mach number, altitude, drag indices, and angle-of-attack were computed digitally using table look-up techniques. The flight control system was also implemented in analog fashion on the AD-4.

All digital data required either for the cockpit display or for the TSD electronic map graphics or the projected map positioning was handled by the PDP-11/20 functioning as an I/O handler. The Status Display data was passed to and from the cockpit, while the map graphics and positioning data was passed to the PDP-11/03. The graphics data was further processed by the Ramtek RM9400 before being piped to the cockpit in video format.
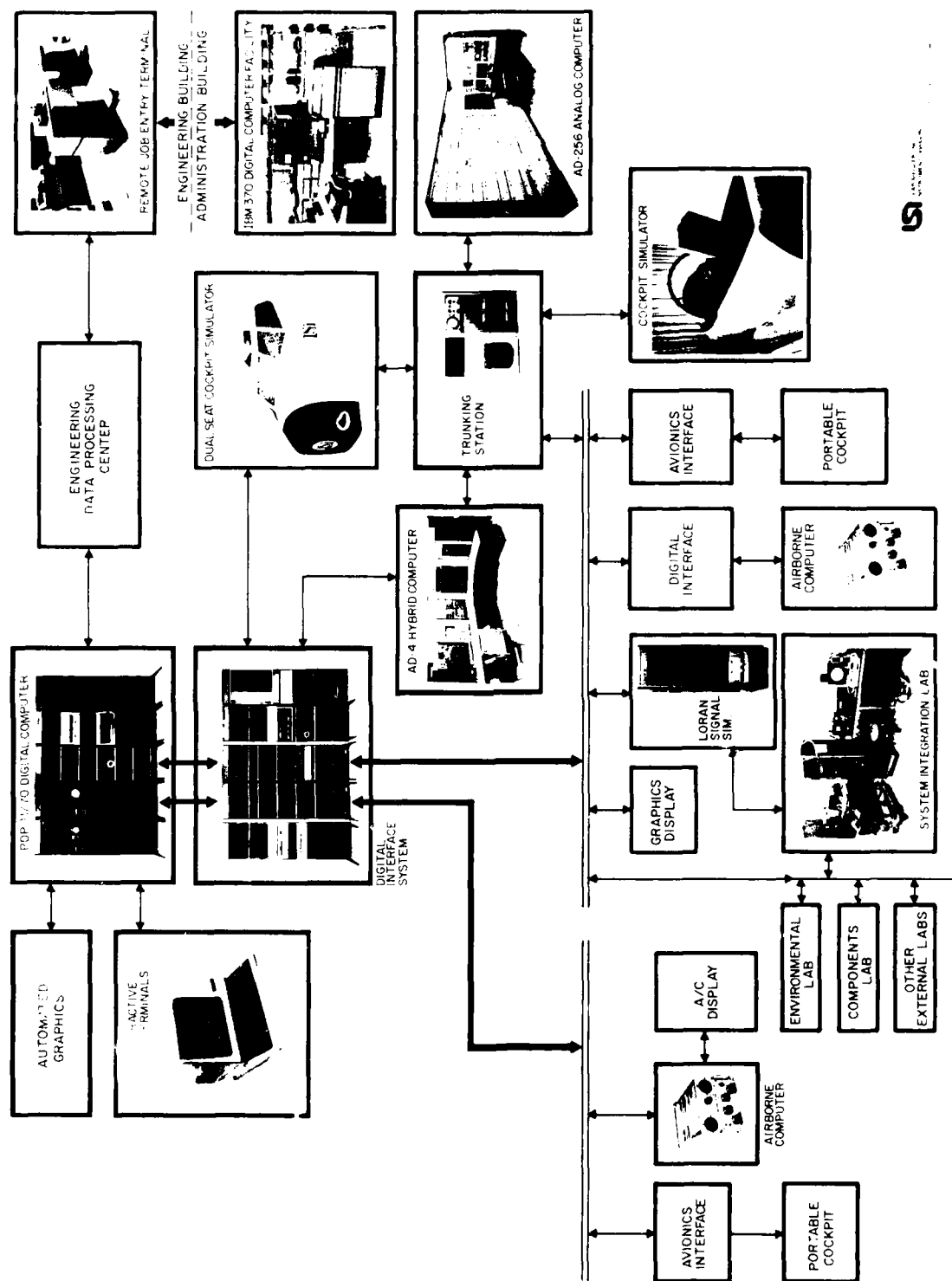
SIMULATION/ANALYSIS/TEST FACILITY AND CAPABILITIES

Figure 44. Simulation/Analysis/Test Facility and Capabilities

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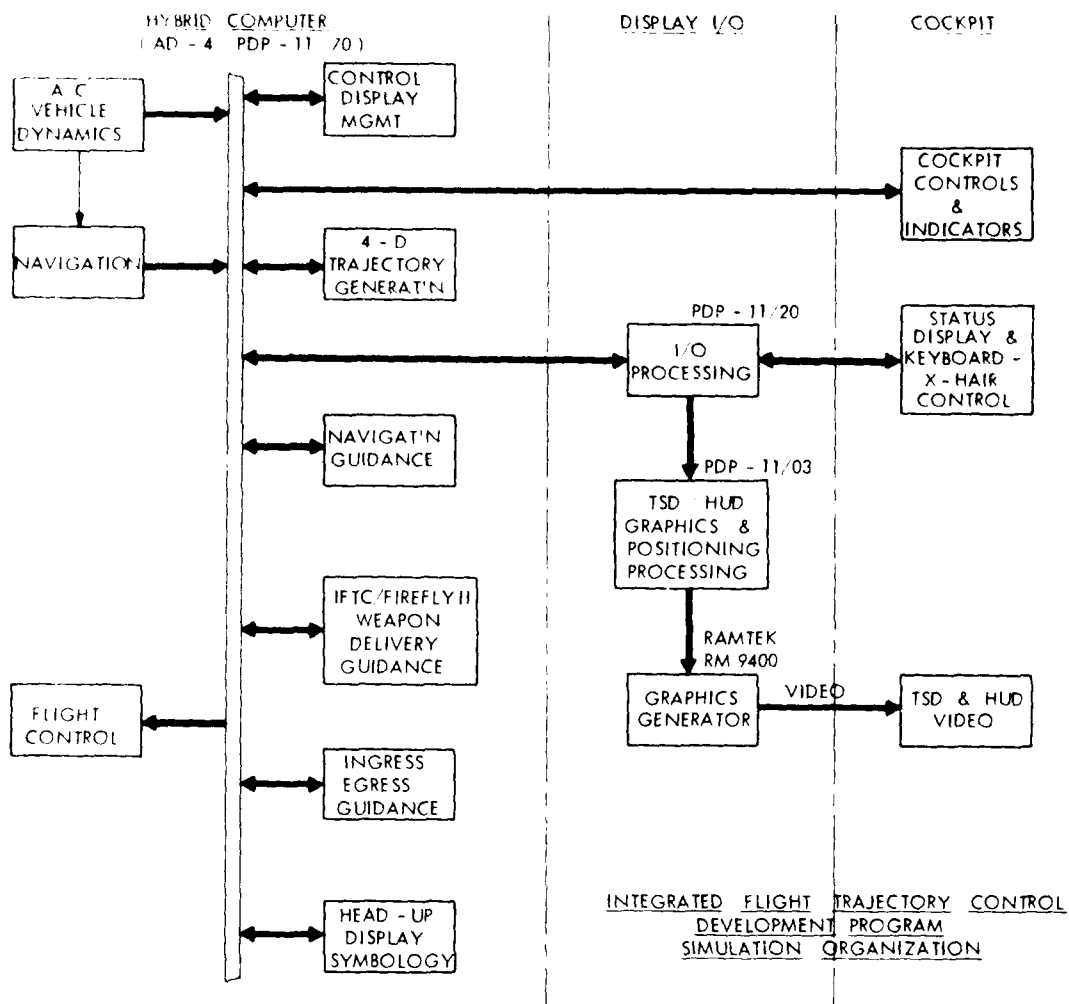
Figure 45. Simulation Organization

The remainder of the cockpit instruments are driven by either DC analog or synchro signals via digital-to-DC or digital-to-synchro converters. The cockpit-controlled outputs (side-stick controller, throttle, and rudders) were passed directly to the AD-4 analog interface lines.

Because the program involved pilot-in-the-seat testing, it was necessary to configure the simulation to run in real-time. The basic interrupt-driven routine, which scheduled all other tasks, was driven at a 50-ms interrupt rate.

Appendix C describes the simulation in further detail.

8 RECOMMENDATIONS FOR FUTURE WORK

The IFTC Development Program has demonstrated the usefulness of a bulk data transfer and ground-based mission planning system, an electronic/projected map tactical siutation display, and the integration of IFTC and Firefly II advanced weapon delivery for ingress/egress coordination and control.

Each of these additions to the IFTC technology base represent necessary elements of a tactical flight management system. In the spirit of providing further development of a tactical flight management system, the following are offered as recommendations for future work.

- Fuel savings/energy management - With fuel costs ever increasing, saving fuel in as many ways as possible is becoming increasingly more important. IFTC has previously demonstrated that time coordination can save fuel, whether it be by elimination of the customary Air Refuel Initial Point (ARIP) to Air Refuel Couple Point (ARCP) leg, or by elimination or reduction of the typical time spent in loiter for a fighter escort rendezvous, as typical examples.

  Saving fuel is also possible by controlling the aircraft or by providing pilot advisories for manual aircraft control to maintain near-optimum engine operating conditions. The commercial aircraft industry has been flying fuel saving systems for several years. LSI's involvement with fuel savings devices began in 1973, with the first revenue flight equipped with an LSI Performance Data Computer (PDC) occurring in 1977. Presently, there are 200-250 commercial aircraft equipped with PDC, with an additional 500 having been ordered.

  While the military operations certainly differ from the commercial, similarities do exist, and the opportunities for fuel savings are present. Climb, cruise, and descent phases of flight lend themselves to fuel-saving techniques, particularly on the friendly side of the FEBA. Extension of the technology would be made to handle supersonic as well as subsonic flight conditions. Analysis has shown that each 500 pounds of fuel saved relates to the following uses:

  a. 1 minute of afterburner @ 40000', or,
  b. 1 minute of military power @ sea level (S/L), or,
  c. 20 nm of increased range @ S/L, or,
  d. 40 nm of increased range @ 20000', or,
  e. for each 100 nm @ S/L, TAS may be increased from 420 kts to 540 kts, corresponding to 50% less losses/sortie

- Under separate contract to the Air Force[11], LSI has demonstrated the feasibility for a full color, digital electronic TSD. All features are stored as digital data and reproduced by a graphics processor. The EPMD used in the current study projects the tactical planning map detail from a 35 mm film strip and optically combines this information with the CRT-displayed flight plan information. Unlike the EPMD, the all-digital TSD will generate both flight plan and tactical map information in raster format for display on a high-resolution, color CRT.

  Preliminary results indicate that a typical 120 mn-by-120 nm tactical map section near the Fulda, Federal Republic of Germany, may be reproduced by approximately 60,000 graphic vectors and includes the following features:

    - Rivers (major and minor)
    - Cities and villages (with metropolitan boundaries)
    - Lakes
    - Railroad lines
    - Expressways and major highways
    - Minor highways
    - Power lines
    - Vertical obstructions (towers, etc.)
    - Terrain features

  If a properly sized, high-resolution color CRT becomes available, it is recommended that LSI install such a CRT in the IFTC cockpit in place of the EPMD, and drive it with our digital map hardware and software. This will allow pilot exposure to such a system, and help determine the usefulness of certain classes of geographic features, and the use of color for feature discrimination.

- The Purple Haze program[12] is concerned with ground threat locations and local terrain features to establish areas of relative flight safety as a function of altitude (AGL) and position. The safe areas are determined by terrain masking of the threat radar coverage. While this technology establishes safe areas, it does not determine the optimum or near-optimum trajectory through or between these areas.

  It is recommended that the technology be pursued for utilizing the IFTC trajectory generation capabilities and path optimization techniques for establishing flyable, curvilinear paths representing minimum exposure profiles through the threat array.

  The data base for the digital Tactical Situation Display could be used to provide terrain feature data for the Purple Haze algorithms.

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- Trajectory generation and precise time control can provide many new capabilities on the hostile side of the FEBA. Among the possibilities are:

  - Multi-aircraft time coordination of threat saturation on ingress

  - Minimum exposure paths for real-time threats

  - Minimum exposure profile reference for terrain following/terrain avoidance (TF/TA) systems

  - Weapon delivery set up for "preferred-axis" attack, especially using the advanced air-to-ground delivery technology

  - Time control for near-simultaneous target attack

  - Dynamic redirect for hunter/killer operations

A promising capability could be achieved by using the IFTC trajectory/time control capability for precise time-coordinated, multiple aircraft strike missions. This technique would involve controlling the aircraft in the strike flight to arrive at a defined point near the target area at a specified time. This time would be determined by mission planning and adjusted en route by AWACS or the FAC, and would be determined as a function of ECM support, combat air support, or other time-critical factors related to the target (target convoy is traversing a narrow canyon, and is vulnerable, etc.) This time/space point would serve as the branching point for the coordinated attack on the target. As a function of the target area geometry and/or the terrain and defenses, an attack initiation point (AIP) would be computed for each aircraft (typically 4). IFTC would compute a trajectory from the branch point to each aircraft's assigned AIP. At the AIP, each aircraft would execute a maneuvering a/g weapon delivery attack on the target.

If a preferred axis of attack on the target is desirable, this bomb pattern azimuth is "worked back" from the target to the AIP in the form of a ground track to be satisfied. The IFTC trajectory for each aircraft satisfies the desired ground track at the AIP. The offset bombing capability afforded by the IFTC/Firefly technology allows near-simultaneous target attack along a preferred axis without the dangers of mid-air collisions and bomb fragmentation interference.

Use of time control to the branching point and individualized trajectory generation for each aircraft to the AIP results in nearly simultaneous attacks on the target, with each aircraft attacking from a different quadrant with respect to the target, for maximum confusion and tracking difficulty for the ground defenses.

Other variations of this attack scenario are possible. For instance, the lead aircraft (hunter) may begin its "pop" maneuver sufficiently ahead of the remaining aircraft in the attack flight. The hunter acquires the target, determines its heading if mobile, and telemeters this information to the remaining aircraft via a data-link. This allows the trailing aircraft (killers) to perform shallower pop maneuvers and acquire the target much faster because of the information supplied by the hunter.

Another variation is possible by properly using IFTC trajectory generator and the offset capabilities of the IFTC/Firefly, to attack the target in a counter-heading formation. That is, two aircraft drop bombs or missiles along the preferred attack axis heading, while the remaining aircraft attack along the opposite heading. Again, advanced maneuvering and off-set bombing techniques greatly reduce the possibility of mid-airs for the attack phase.

It is recommended that these technologies be developed and implemented in the IFTC simulator. The Ferranti EPMD would be replaced by a high-resolution, 5-inch color monitor driven by an appropriate high-speed color graphics processor. Trajectory generation and time control would be combined with optimal fuel management. Additionally, trajectory generation would be refined to handle minimum exposure profiles through the Purple Haze threat footprints, and time control would be extended to enable multiple aircraft, simultaneous strike scenario.

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APPENDIX A

INGRESS STEERING LOGIC

AND FLOW CHARTS

A.1 IFTC/FIREFLY-II W/D INTEGRATION

STEERING AND ALERT LOGIC

The weapon delivery maneuver geometry is predicted based on pilot selection of maneuver parameters and constraints. The resulting maneuver conditions are provided to the IFTC algorithms for computation of the proper offset point (or entry point (E/P)). The primary parameters selectable by the pilot are:

- Altitude at initiation of maneuver

- Minimum A/C-to-target penetration distance

- Nominal angle-off from the start of the maneuver until release occurs

- G loading during the delivery

- G loading during egress

Secondary parameters which may be specified are roll angle after release, exit track angle relative to target, bomb ripple path angle, and entry velocity.

The E/P coordinates are computed with respect to the target position as X_p, Y_p. The locus of X_p, Y_p is a circle of radius, R, centered at the target position where

$$R = \sqrt{X_p^2 + Y_p^2}.$$

X_p and Y_p are computed as,

$$X_p = R_{RMIN} \cos (\omega Tr) + R_{TD} \sin (\omega Tr) \qquad (A-1)$$

$$Y_p = R_{YP} \cos \beta \qquad (A-2)$$

where

$$X_p = \text{along-track coordinate}$$

$$Y_p = \text{cross-track coordinate}$$

R_{RMIN} = bomb range at release, to satisfy D_{MIN}

D_{MIN} = specified minimum penetration dist ince

$_\omega Tr$ = specified angle-off value

R_{TD} = turn radius during the delivery maneuver

R_{YP} = ground projection of Y_p

μ = inclination of the delivery plane

Figure A-1 illustrates the delivery geometry. The steering command for controlling the lateral error of the aircraft with respect to the desired path is

$$\psi_c = \frac{K\ (Y_p - Y_{TGT})}{X_{TGT}} \tag{A-3}$$

where

$X_{TGT},$ = along- and cross-track distances from the A/C
Y_{TGT} position to the target

K = steering gain

Because of the relative way in which the E/P coordinates are computed and utilized by the steering law, the actual E/P location is continuously recomputed and positioned appropriately on the circle about the target, as a function of the attack heading of the aircraft. As a result, the E/P position changes as the attack heading changes, for whatever reason. As the aircraft closes on the nominal E/P position, the adjustments become smaller, which precludes large control transients during the final phases of the attack.

The E/P position is also a function of expected delivery velocity and altitude. If the actual delivery values differ from the pilot-inserted values, the E/P position is automatically adjusted to compensate. Changes in altitude and velocity are evidenced primarily as changes in the radius of the locus circle for the E/P. Changes in attack heading affect the angular location of the E/P on the circle.
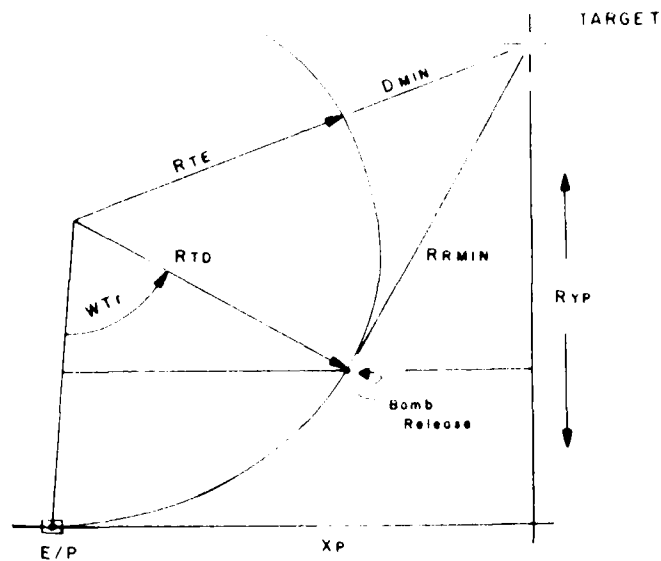
E/P Target Geometry
Figure A-1

The predicted maneuver is determined initially using the inserted minimum A/C-to-target penetration distance. The predicted maximum aircraft altitude attained during the maneuver, which occurs after release for a pop-up delivery, is compared with the inserted maximum altitude constraint. If the comparison is unfavorable (expected higher than desired), two mission parameters are adjusted to reduce the expected altitude and the E/P position is recomputed. The two parameters are angle-off and egress roll angle. Reducing the angle-off decreases the total time in the delivery maneuver which reduces the altitude gained. Increasing the egress roll angle increases the component of the lift vector directed downward during the semi-inverted egress maneuver. This action also reduces the altitude gained after release in a pop-up maneuver.

IFTC provides steering commands, and steering alert discretes which allow the pilot to fly a jinking maneuver when approaching the E/P. The steering alert discretes advise the pilot that he must follow the steering commands which will guide the A/C to the offset point. Failure to follow the commands, either automatically or manually, will eventually result in the display of the break-X indicating to the pilot that he must abort the delivery.

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Figure A-2 shows the steering alert boundaries used by the E/P guidance algorithm. The axes are the values of the magnitude of the relative bearing to target and the range to target. The coordinates of E/P are $(\sqrt{X_p^2 + Y_p^2}, \tan^{-1}\frac{Y_p}{X_p})$, for the coordinates shown.
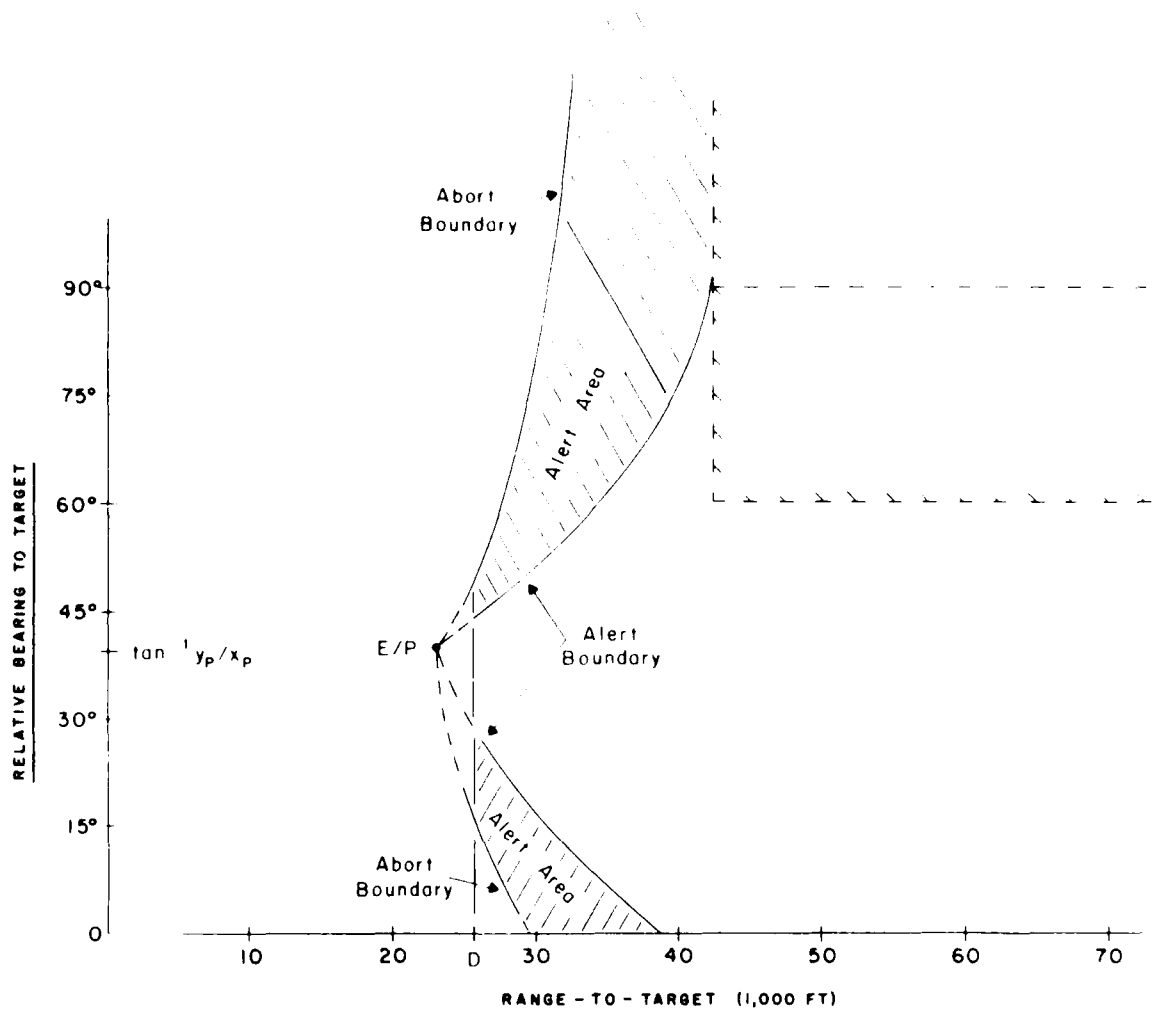
INGRESS STEERING LOGIC

Figure A-2. Ingress Steering Logic

The steering alert and abort boundaries are related to the bank angle required to "steer back" to the E/P. Crossing of an alert boundary is indicated to the pilot by a flashing break-X. As the alert area is penetrated, with no action taken by the pilot, the roll angle required for recovery increases. The flashing break-X warns the pilot that he must either engage the roll autopilot or begin to manually fly the HUD-displayed flight directors. Failure to take action will result in crossing the abort boundary. The pilot is informed of that fact by a steady (non-blinking) break-X over the FPM on the HUD.

The upper alert region is used when the pilot has maneuvered his A/C to place the E/P between it and the target. This is referred to as an outside approach. The lower alert region is used when the pilot has positioned the aircraft between the E/P and the target. Because the magnitude of the relative bearing to target is used, one switching diagram works for either a right-hand or left-hand attack on the target. The E_1 region is applicable for gross acquisition of the target. The steering goal in this region is simply to place the A/C into a 60°, 2-g turn toward the target. As soon as the relative bearing to target is less than 60°, a proportional steering law is used. This region is also used when a re-attack on a target is initiated when the A/C is essentially flying away from the target. A 2-g turn is initiated to bring the A/C back toward the target. The pilot may control the aircraft manually to adjust the re-attack heading.

When the aircraft is within 4 seconds of the E/P, the alert and abort checks are inhibited. This prevents aborting a mission because of relatively small lateral or heading errors when near the E/P. This cut-off value is represented by line D in Figure A-2.

Figure A-3 shows four bombing runs made on the same target, all starting at the same point. Profiles 1, 2, and 3 result in left-hand attacks on the target and 4, a right-hand attack. Profiles 1 and 2 represent jinking maneuvers, but still following the nominal attack profile. Profile 3 represents a drastic departure from the nominal as might be required for a SAM avoidance maneuver. The E/P was automatically re-adjusted without any pilot intervention other than flying the A/C to avoid the threat. All previously in-serted bombing parameters were satisfied by the modified profile.

Profile 4 represents an attack profile modification as a result of the pilot's decision to reverse the attack direction from left-hand to right-hand. This decision was made about 30 seconds prior to reaching the nominal E/P and was performed by simply flying the aircraft to cause the target to lie off the right wing of the A/C rather than the left wing. The E/P guidance algorithm responded automaticaly by recomputing the E/P to position it on the left side of the target. Again, no pilot button-pushing or data entry activity was require.
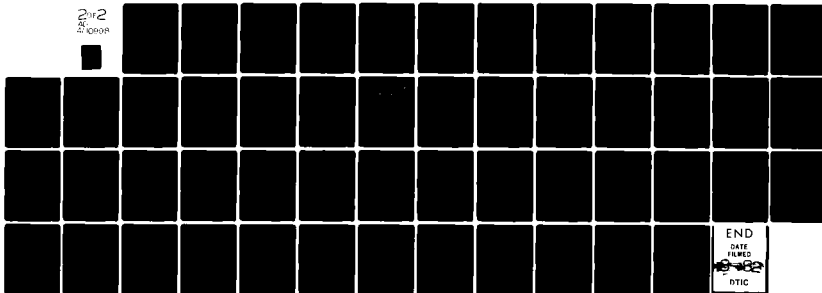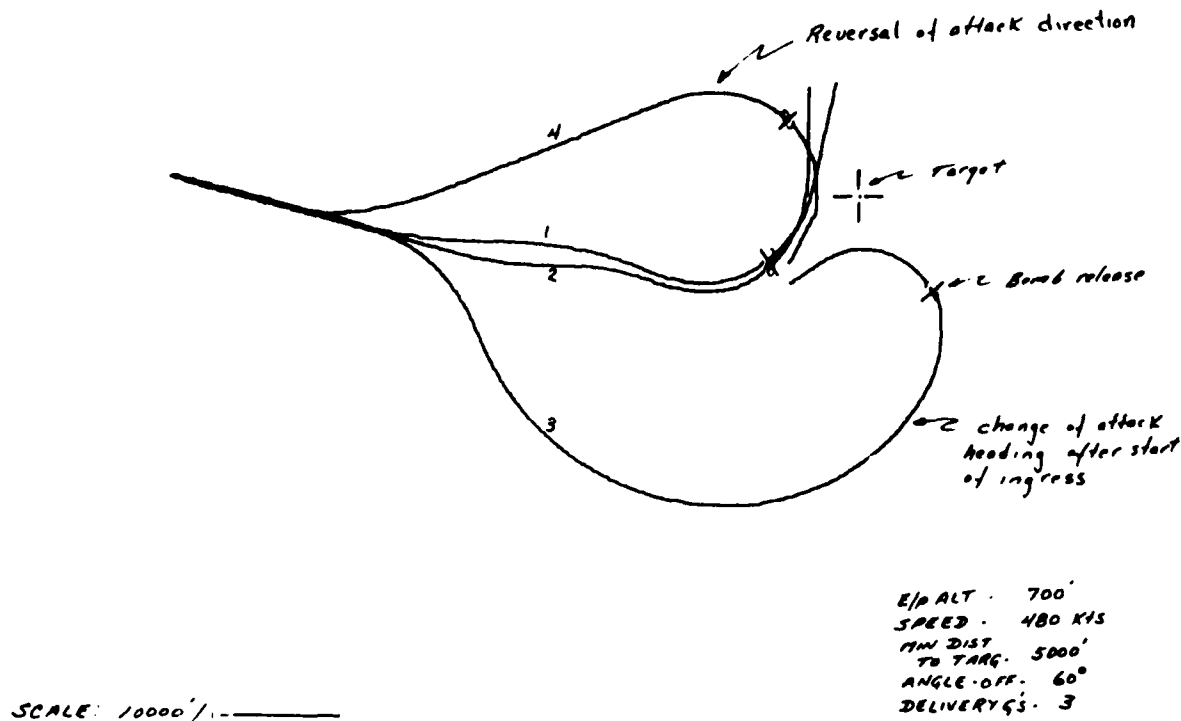
Figure A-3. Four Bombing Maneuvers From Same Initial Position

Figure A-4 shows a nominal attack profile followed by a pilot initiated re-attack on the same target. The re-attack heading was picked by the pilot by simply maneuvering the A/C manually until proper set-up was established. The E/P was computed automatically and guidance to the E/P was provided to the HUD flight directors and the autopilot.

The attached flow charts describe the simulation logic to implement the IFTC/Firefly II design. "ACWDGD" is the calling routine for two initialization suroutines, CRINIT and IWDEPG. Following
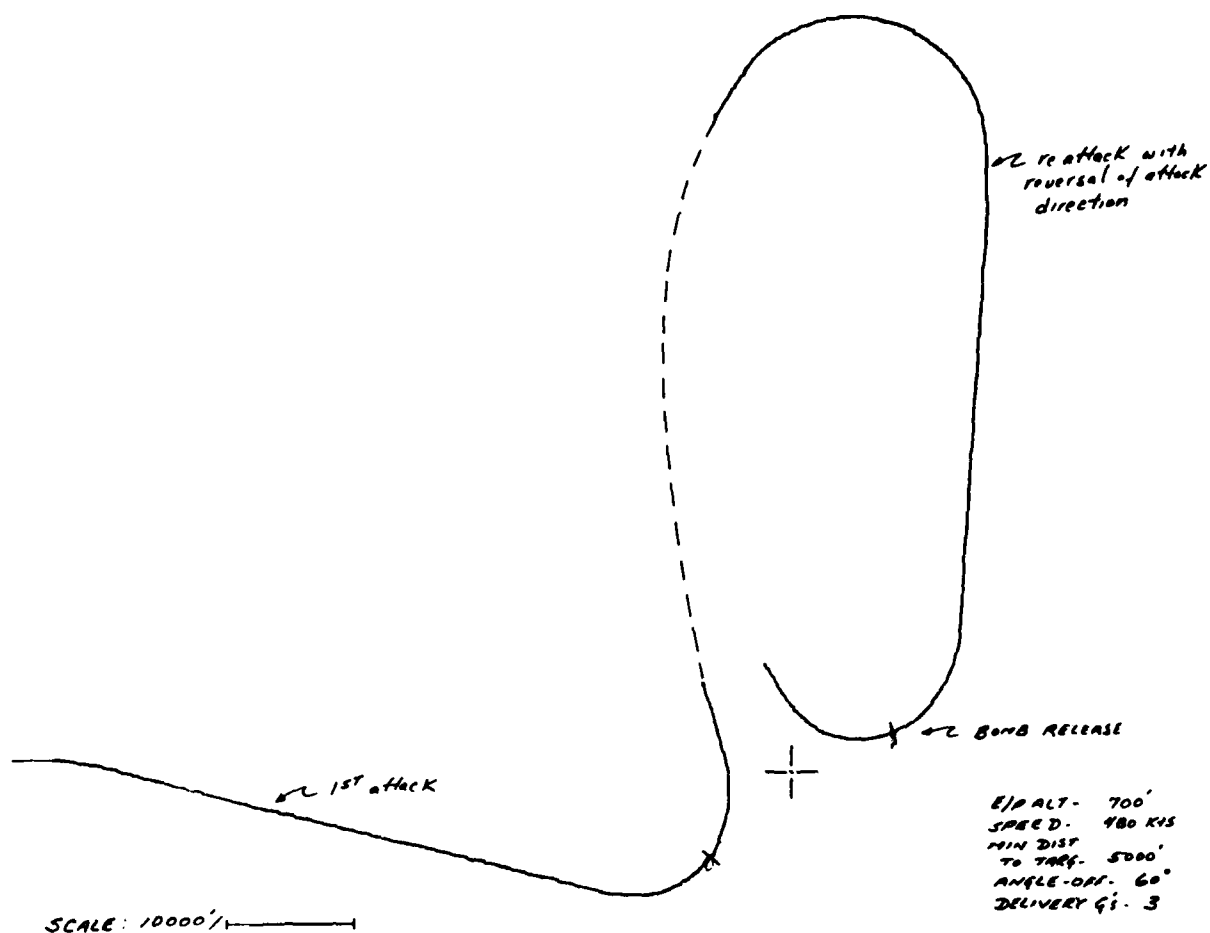
Figure A-4.   Target Re-Attack Maneuver

initialization, it then calls WDPROC (weapon delivery procedures). On the basis of which weapon delivery phase is active -- ingress, delivery, or egress -- WDPPOC issues a call to either CWDEPG (E/P guidance) or CRWDEX (W/D executive).   CRWDEX calls the Firefly II subroutines (not documented in this report) in the proper order, and also calls HUD, the HUD symbology processing subroutine.

ACWDG is included to show the relationship between the weapon delivery subroutines and the total simulation.   Further detail of this relationship is included in Appendix C, Figures C-4, C-5, and the descriptive material.

Figure A-5. IFTC/Firefly II Integration Flow Charts (1 of 21)

Figure A-5.   IFTC/Firefly II Integration Flow Charts (2 of 21)

Figure A-5. IFTC/Firefly II Integration Flow Charts (3 of 21)

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Figure A-5. IFTC/Firefly II Integration Flow Charts (4 of 21)

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Figure A-5.   IFTC/Firefly II Integration Flow Charts (5 of 21)

Figure A-5. IFTC/Firefly II Integration Flow Charts (6 of 21)

Figure A-5.   IFTC/Firefly II Integration Flow Charts (7 of 21)
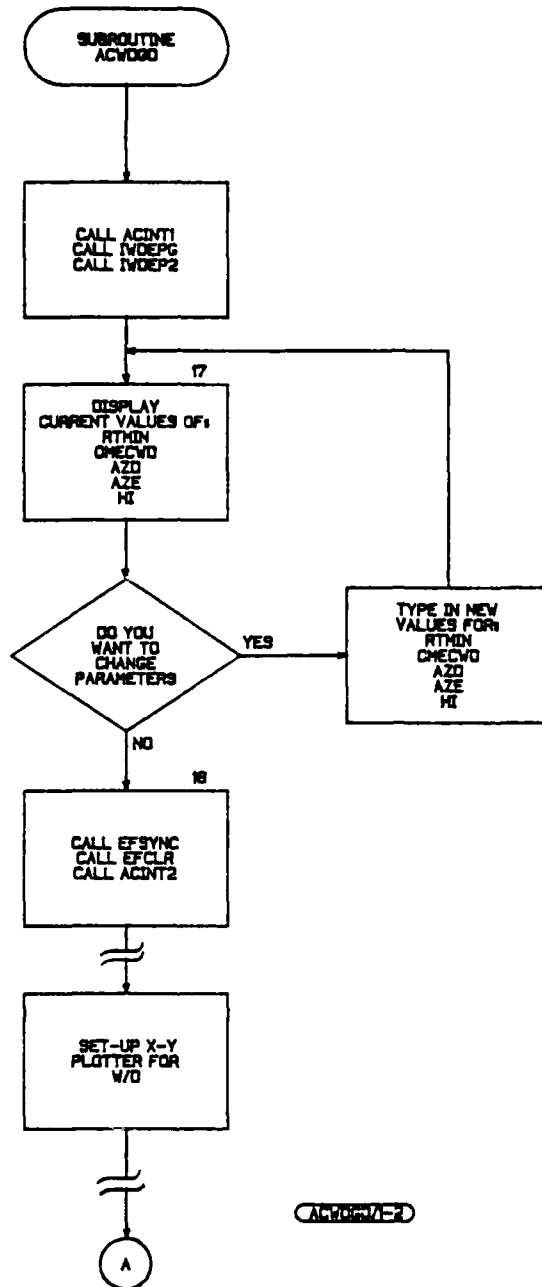
95
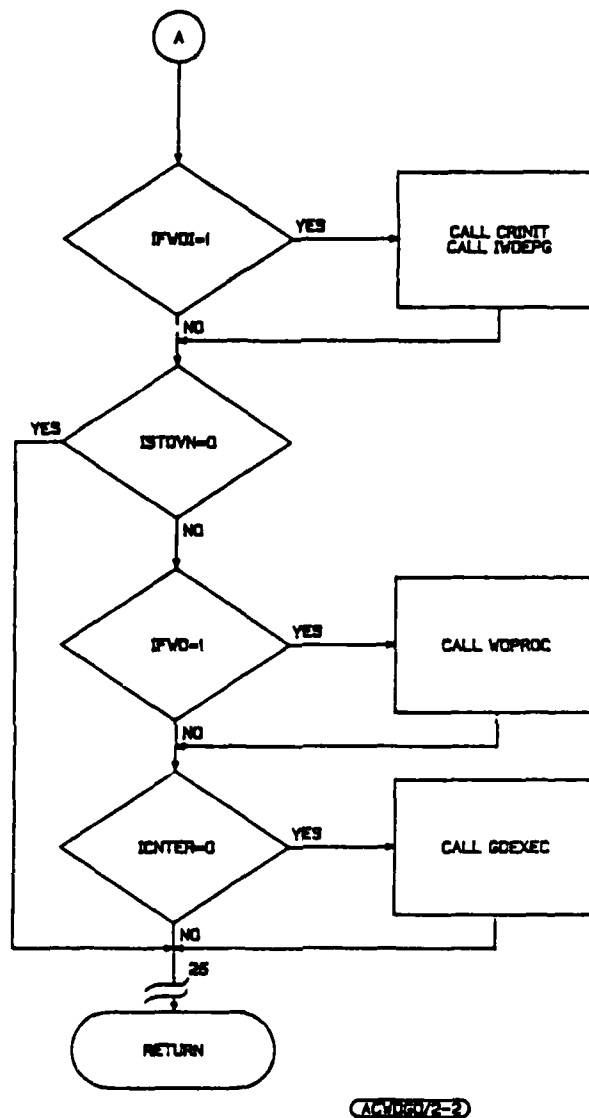
Figure A-5. IFTC/Firefly II Integration Flow Charts (8 of 21)
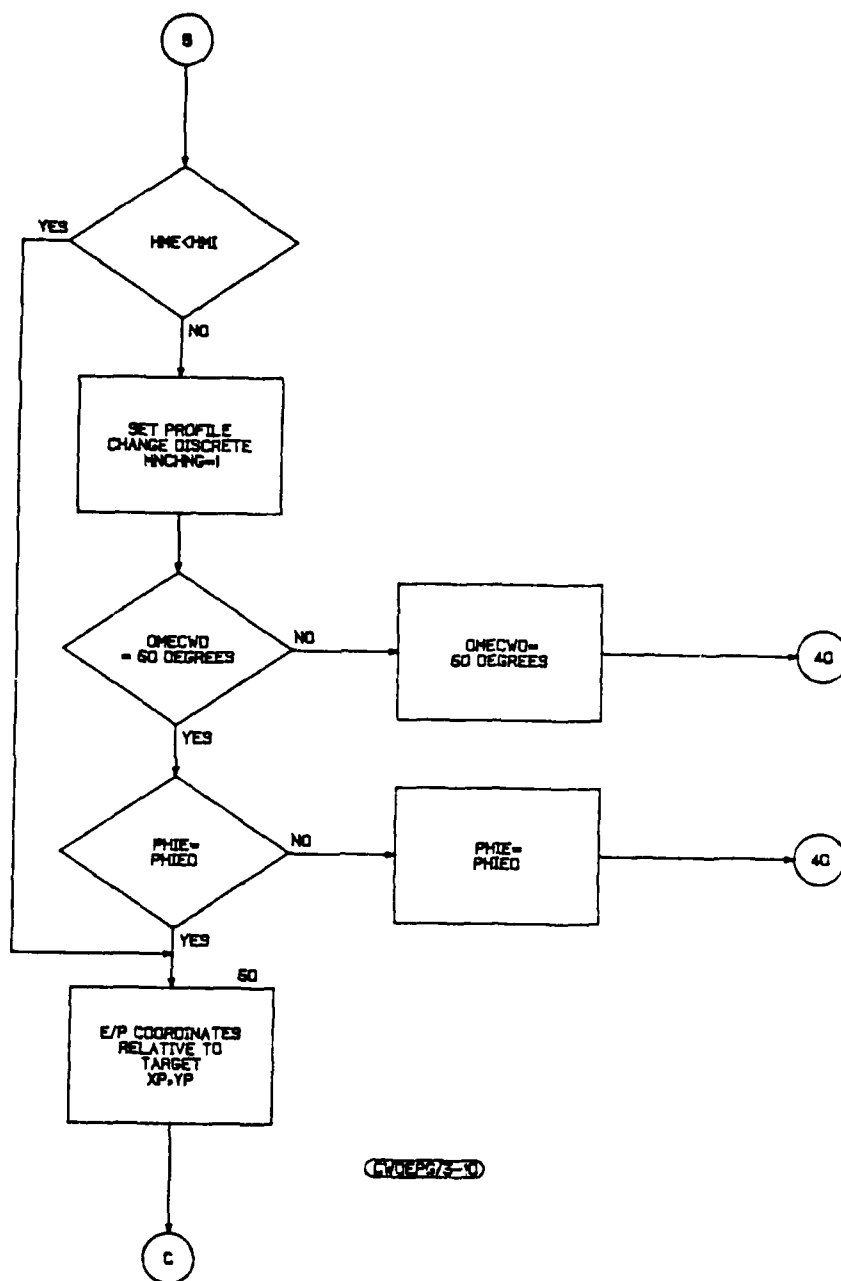
Figure A-5. IFTC/Firefly II Integration Flow Charts (9 of 21)
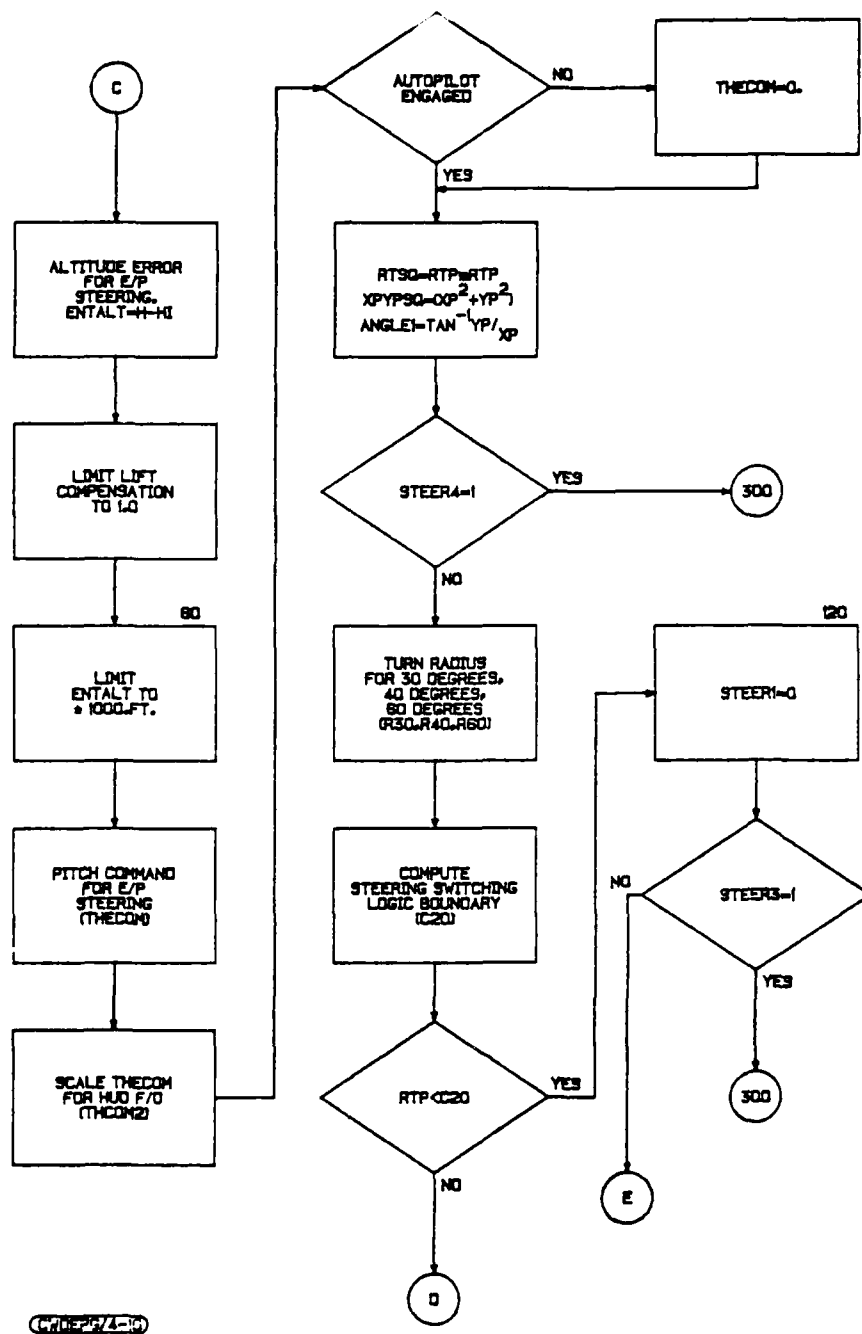
Figure A-5.   IFTC/Firefly II Integration Flow Charts (10 of 21)
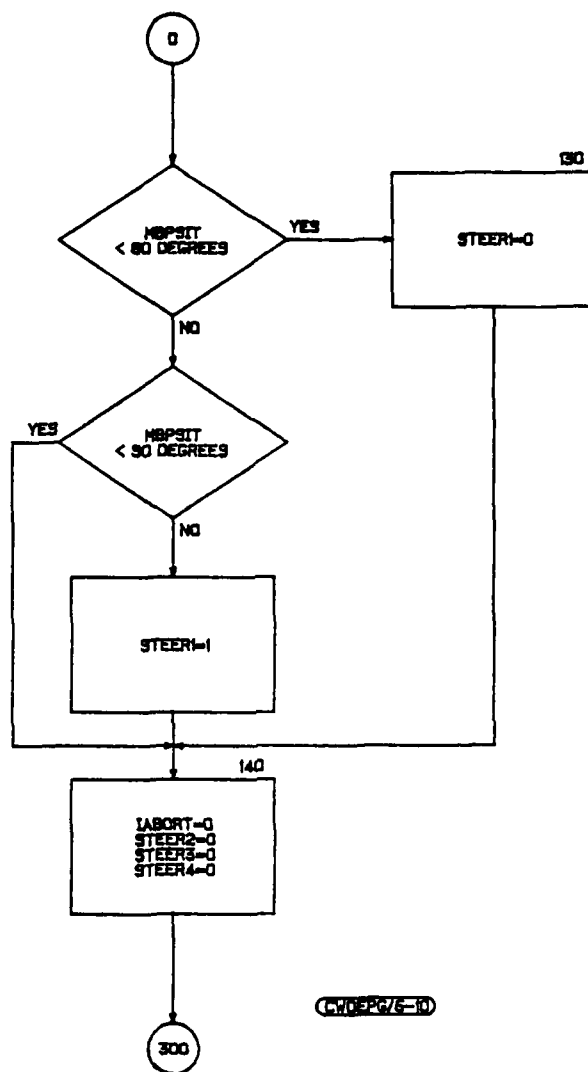
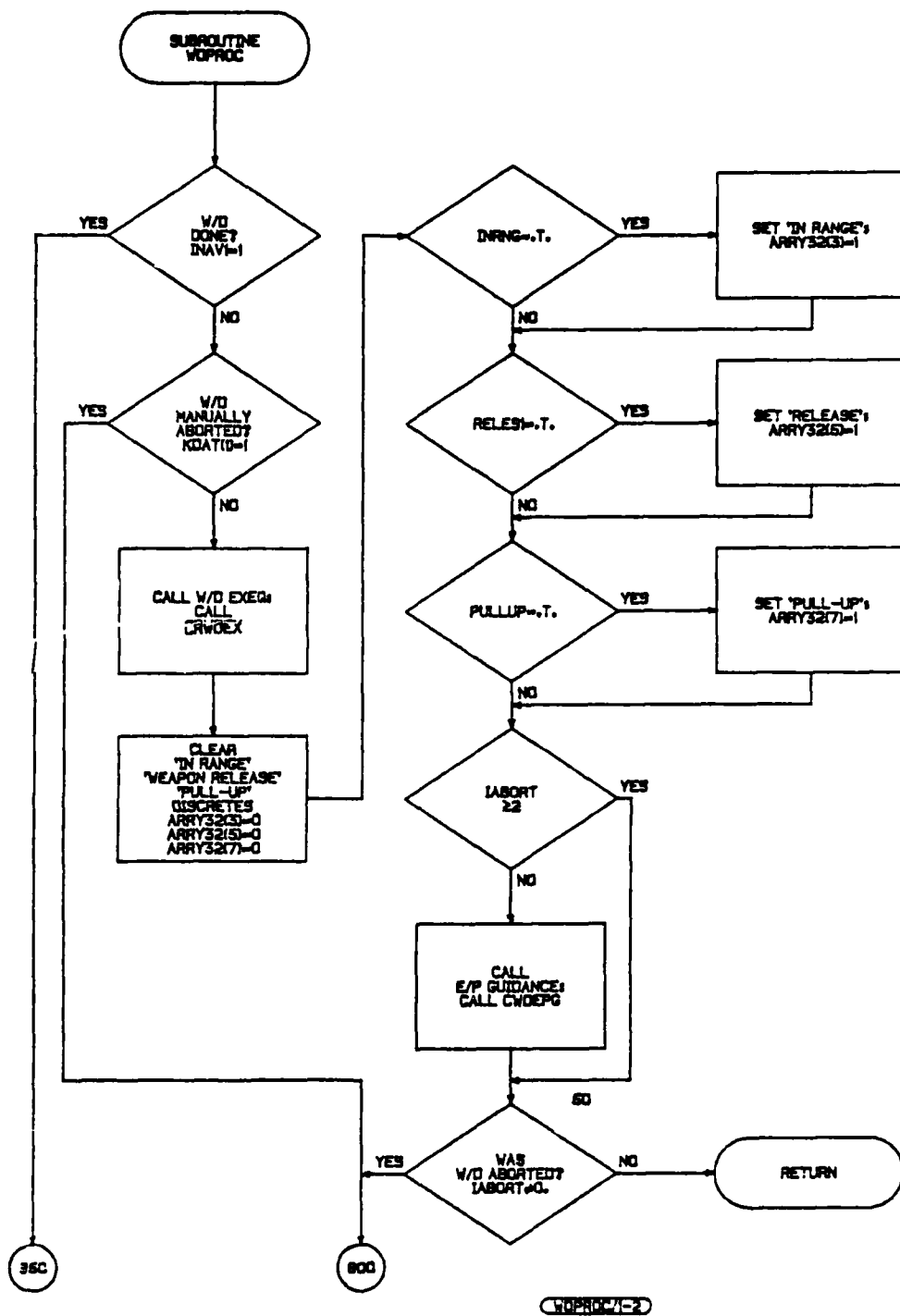Figure A-5.   IFTC/Firefly II Integration Flow Charts (11 of 21)
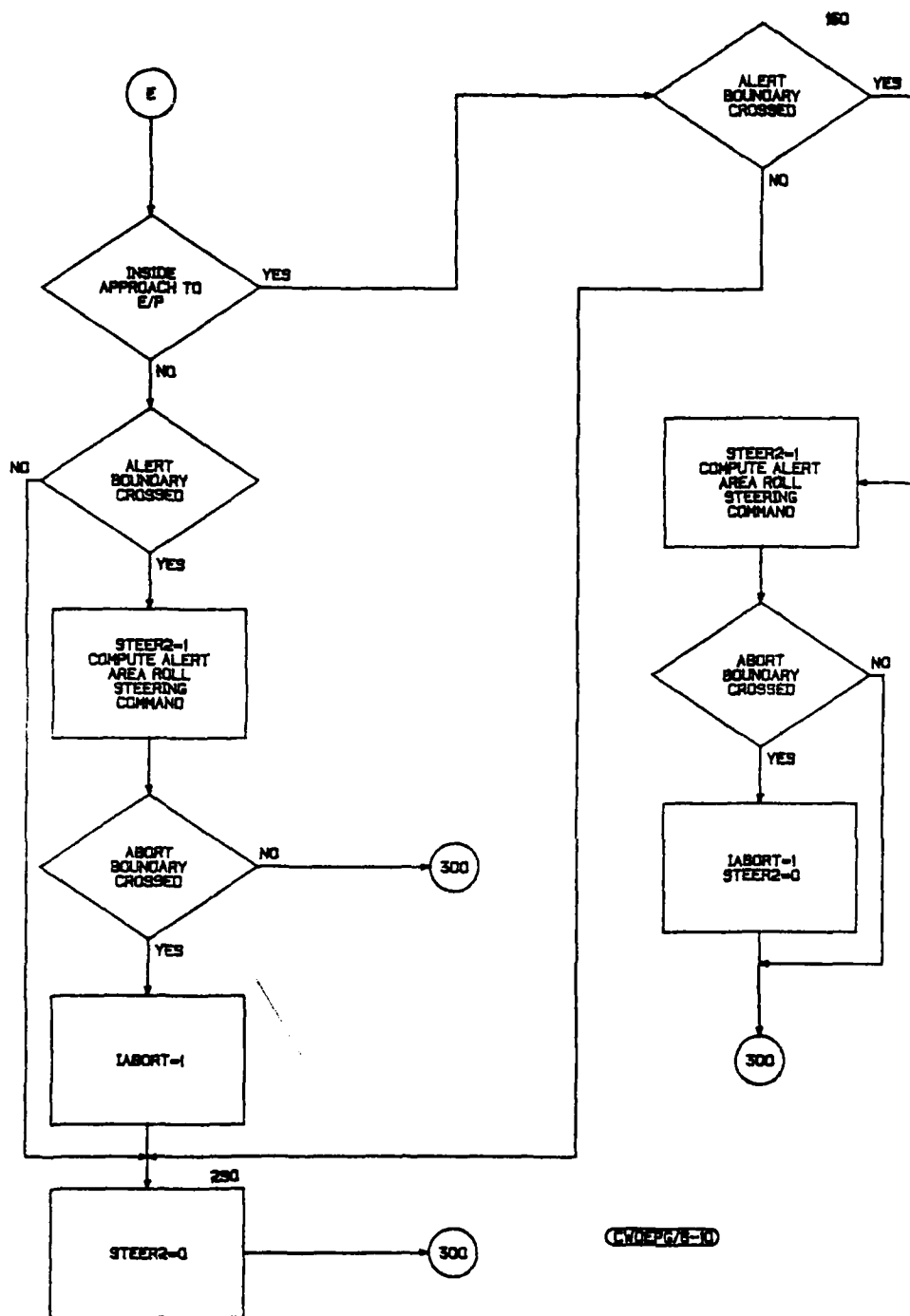
Figure A-5. IFTC/Firefly II Integration Flow Charts (12 of 21)
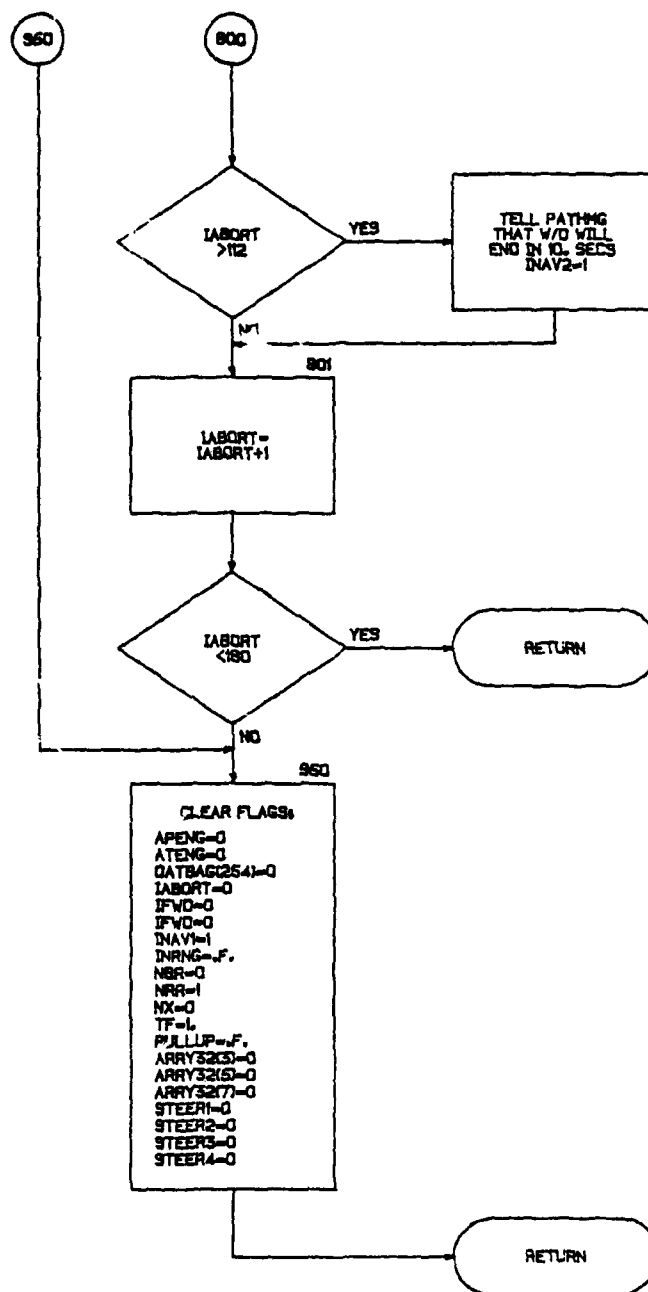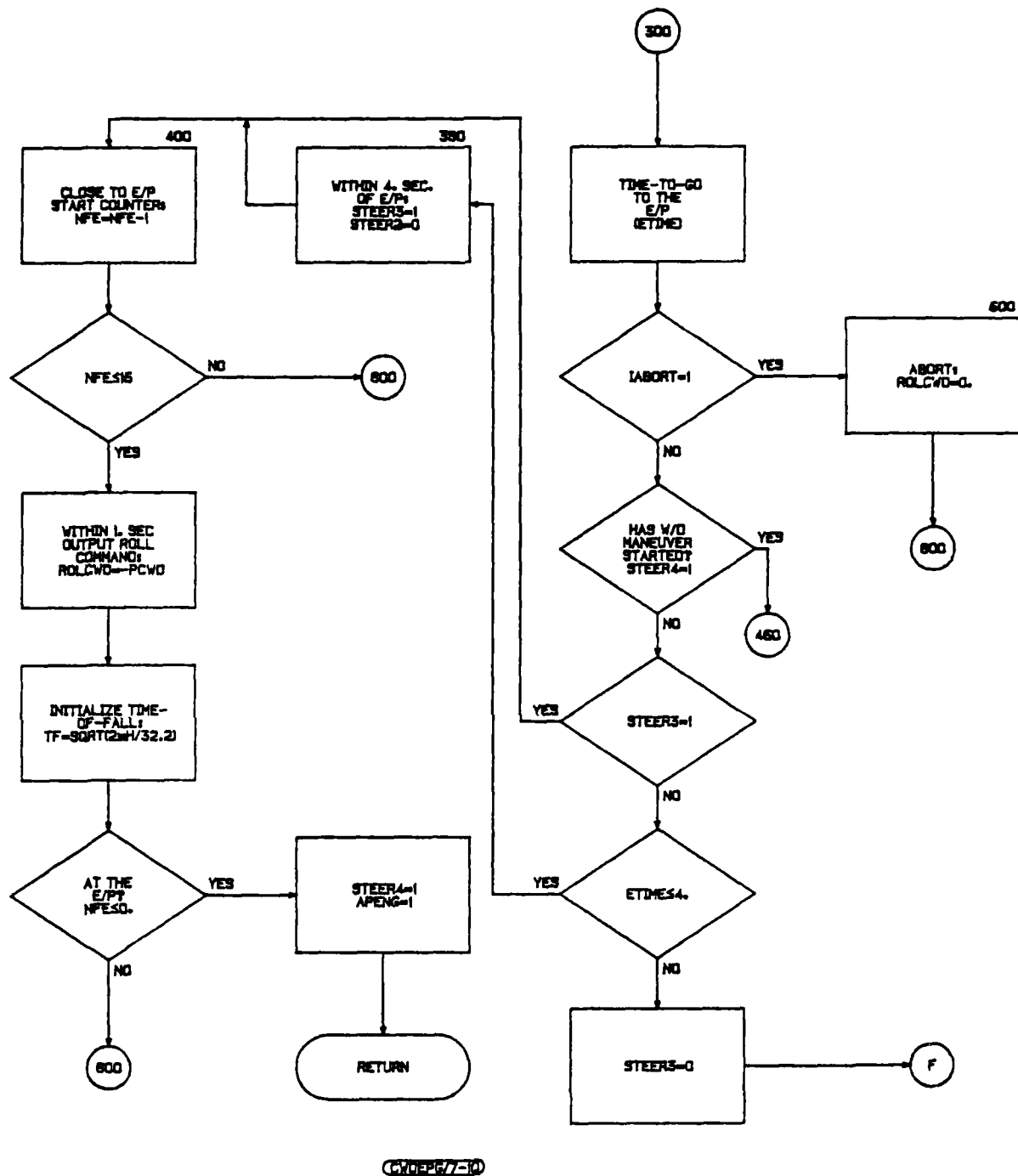
Figure A-5. IFTC/Firefly II Integration Flow Charts (13 of 21)
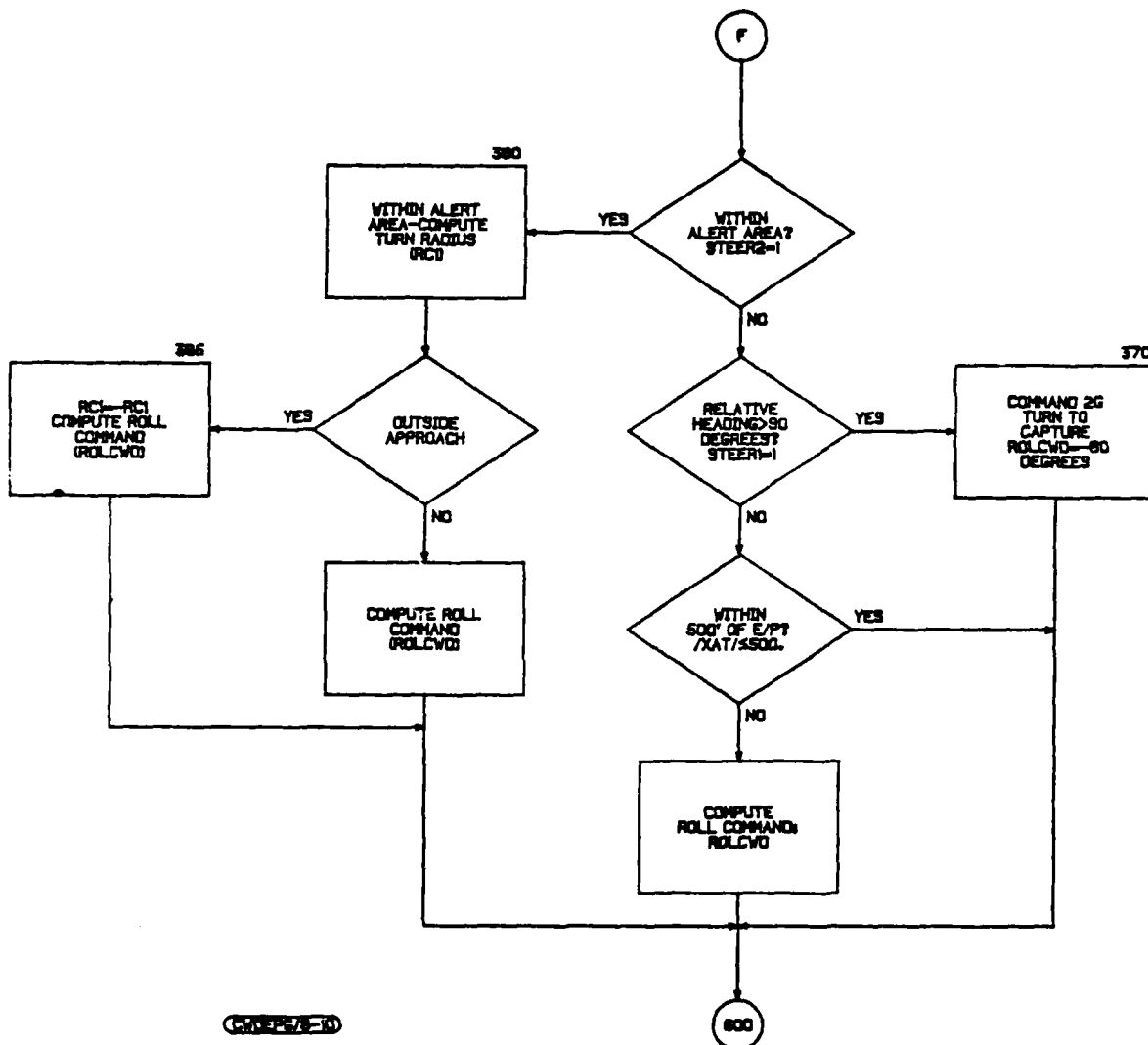
Figure A-5. IFTC/Firefly II Integration Flow Charts (14 of 21)
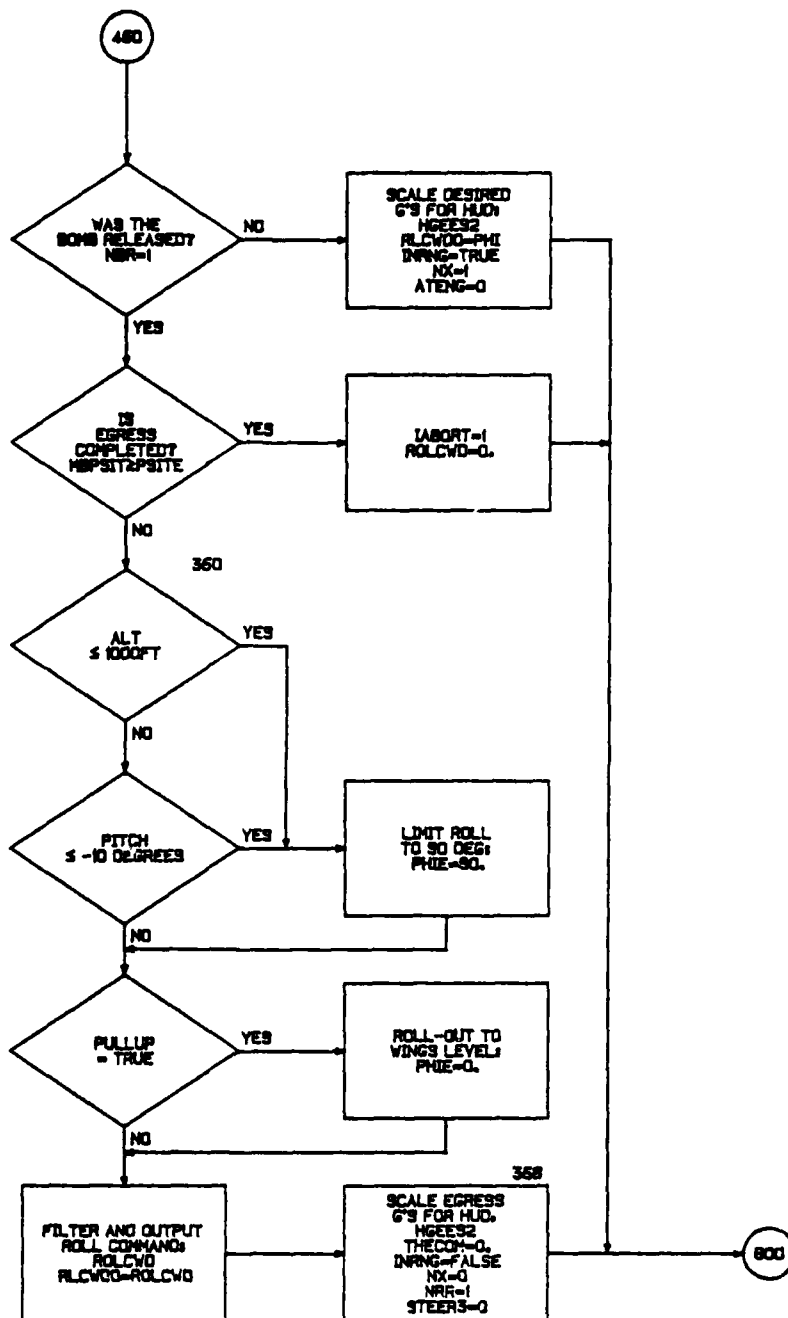
Figure A-5.   IFTC/Firefly II Integration Flow Charts (15 of 21)
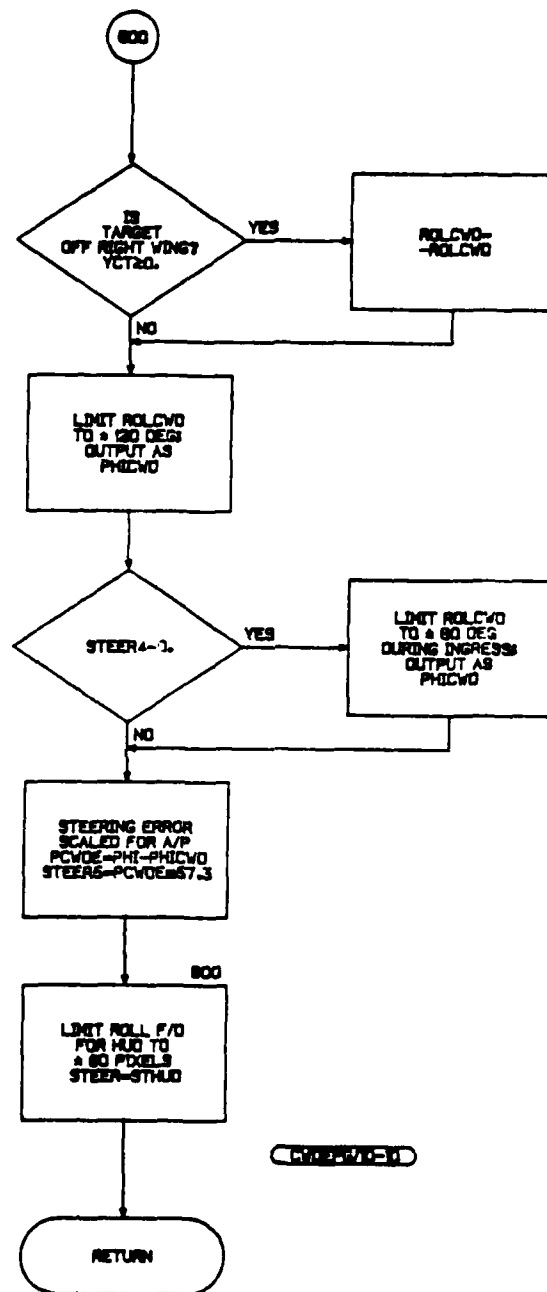
Figure A-5. IFTC/Firefly II Integration Flow Charts (16 of 21)
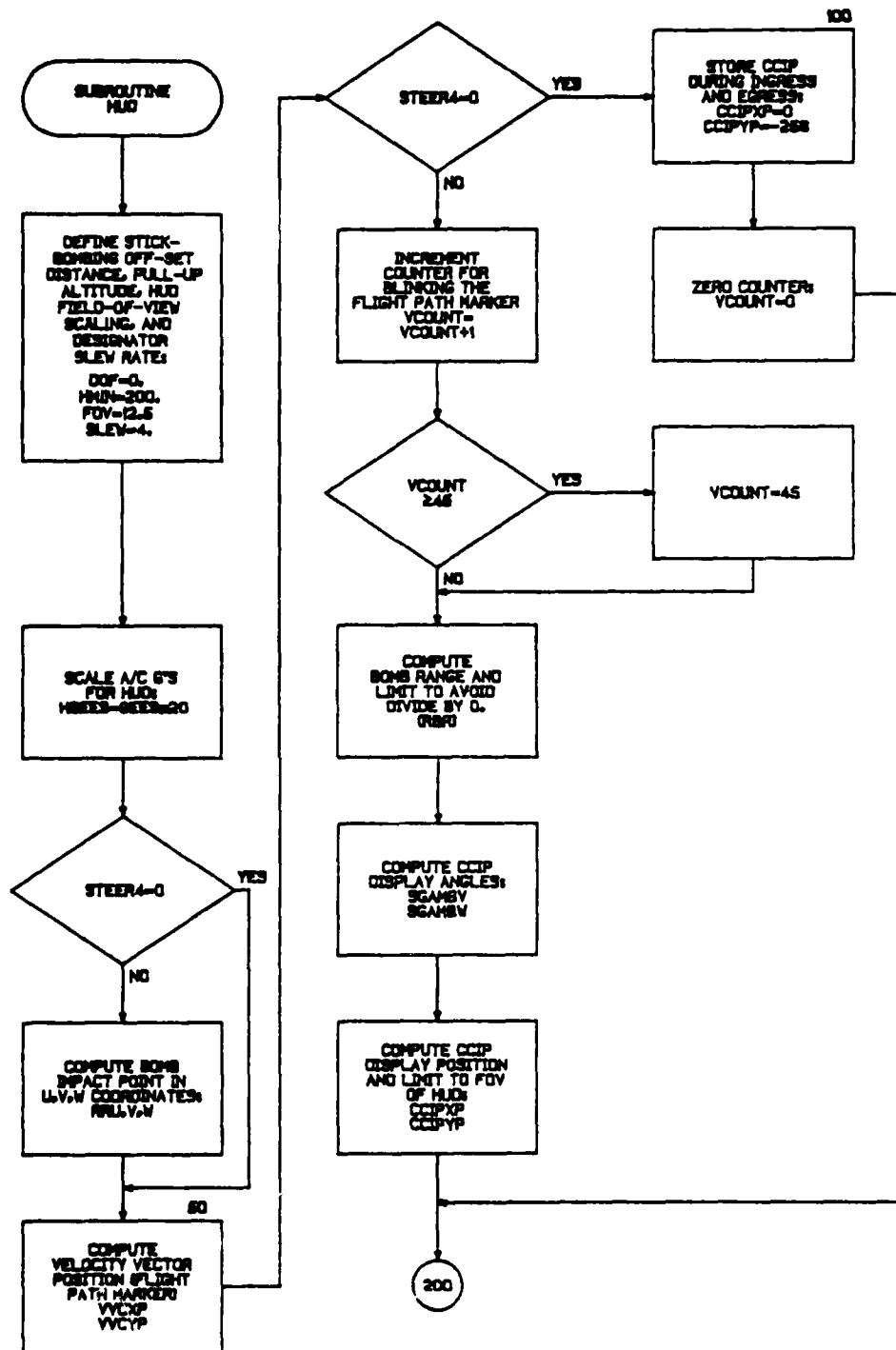
Figure A-5. IFTC/Firefly II Integration Flow Charts (17 of 21)
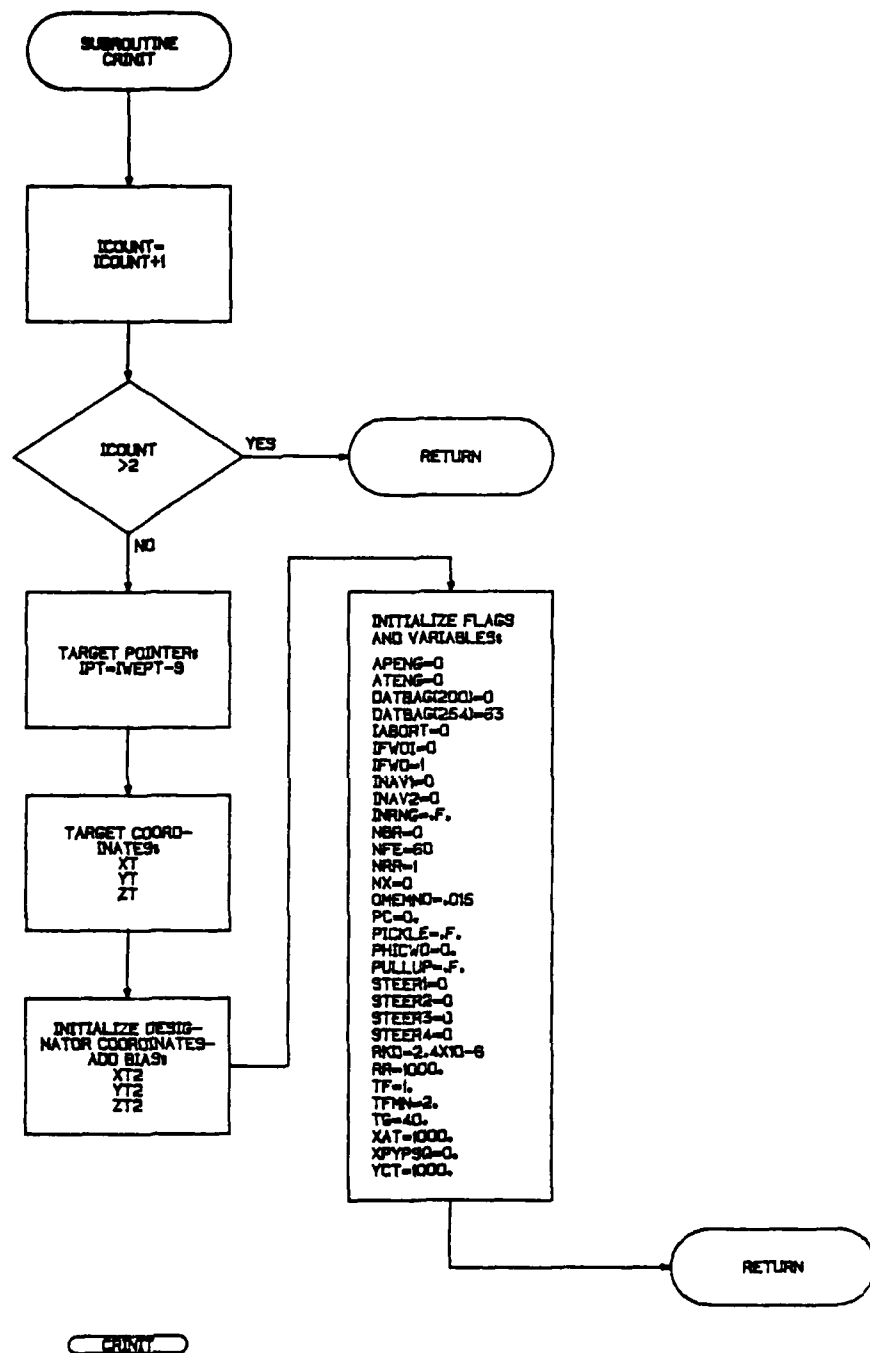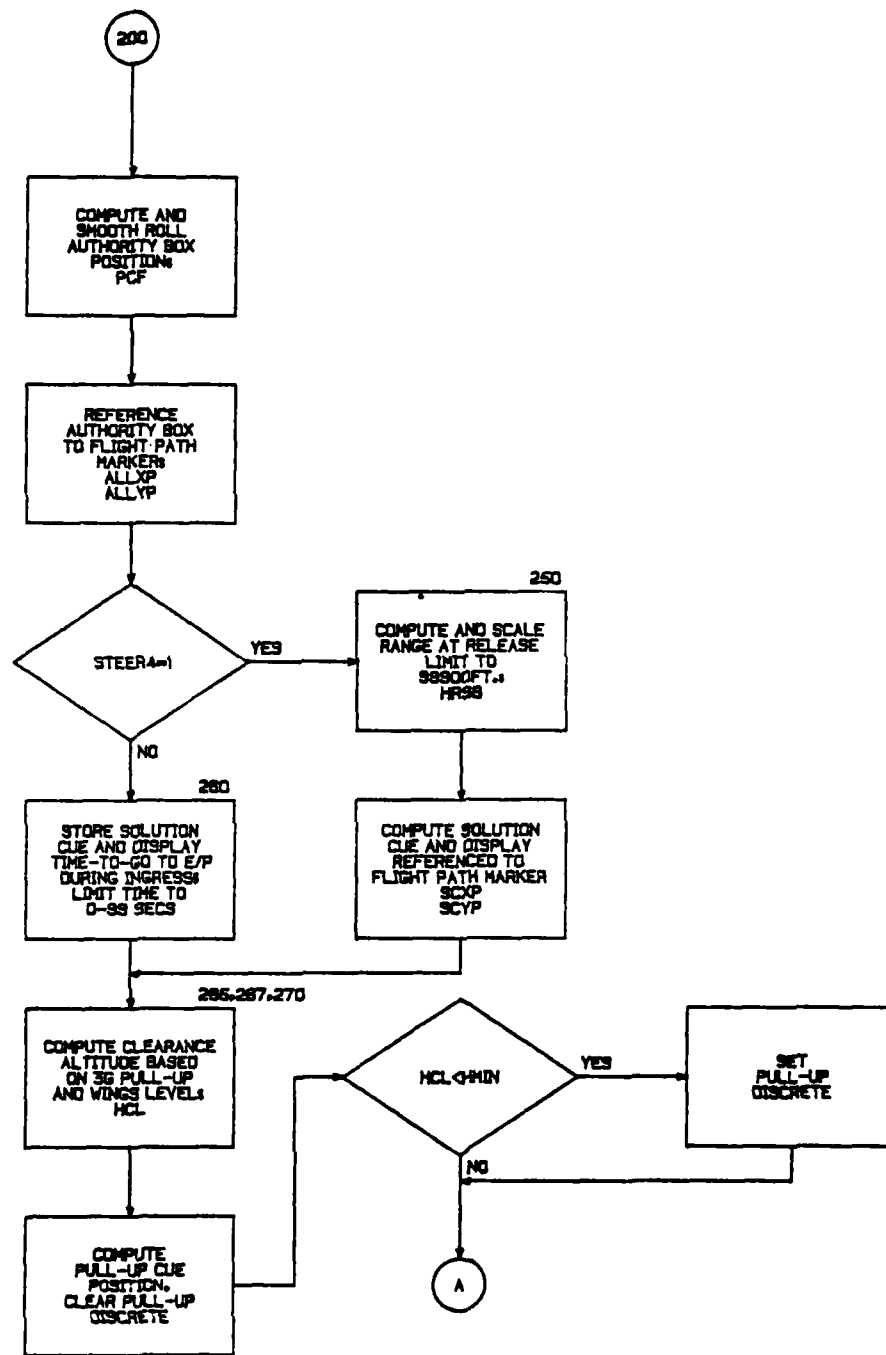
Figure A-5. IFTC/Firefly II Integration Flow Charts (18 of 21)
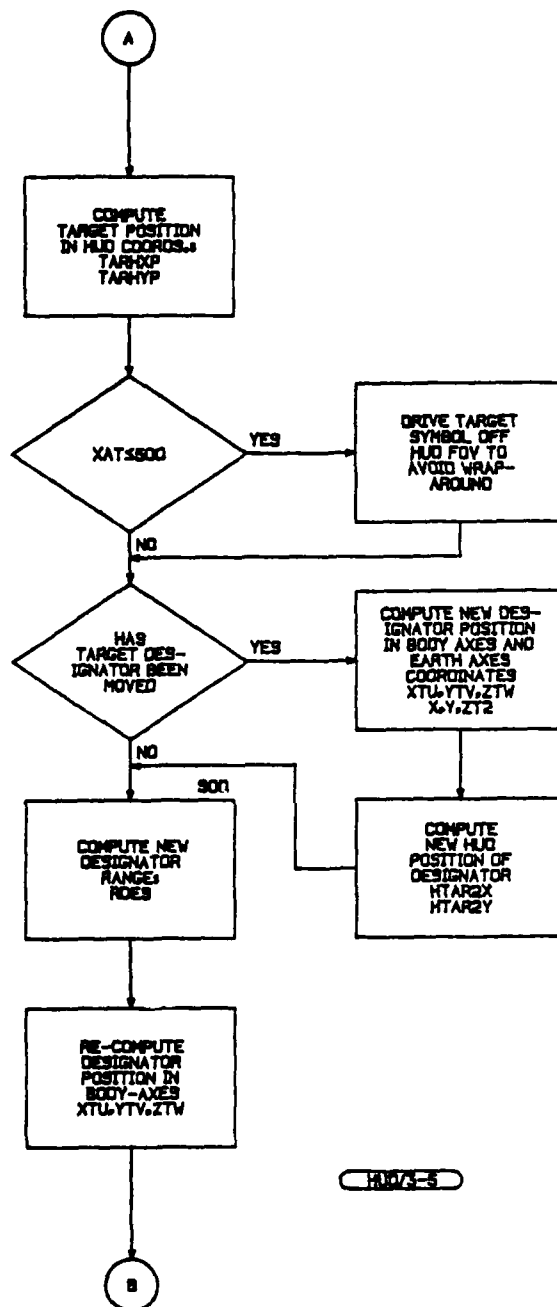
Figure A-5. IFTC/Firefly II Integration Flow Charts (19 of 21)
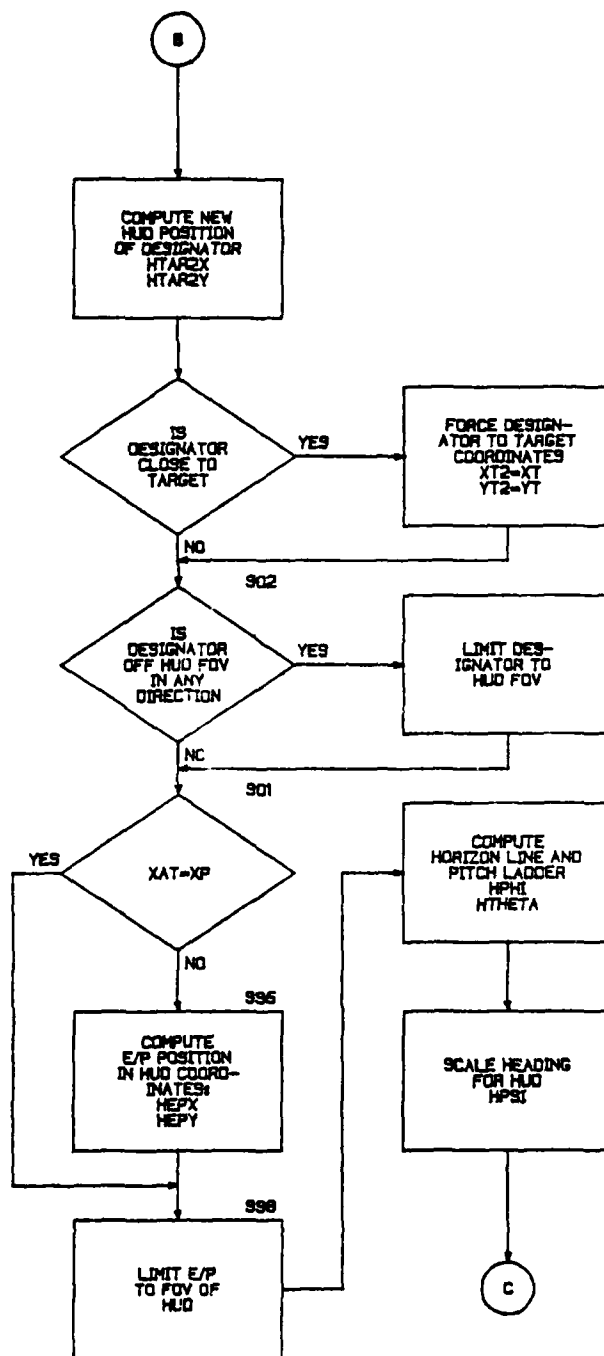
Figure A-5. IFTC/Firefly II Integration Flow Charts (20 of 21)

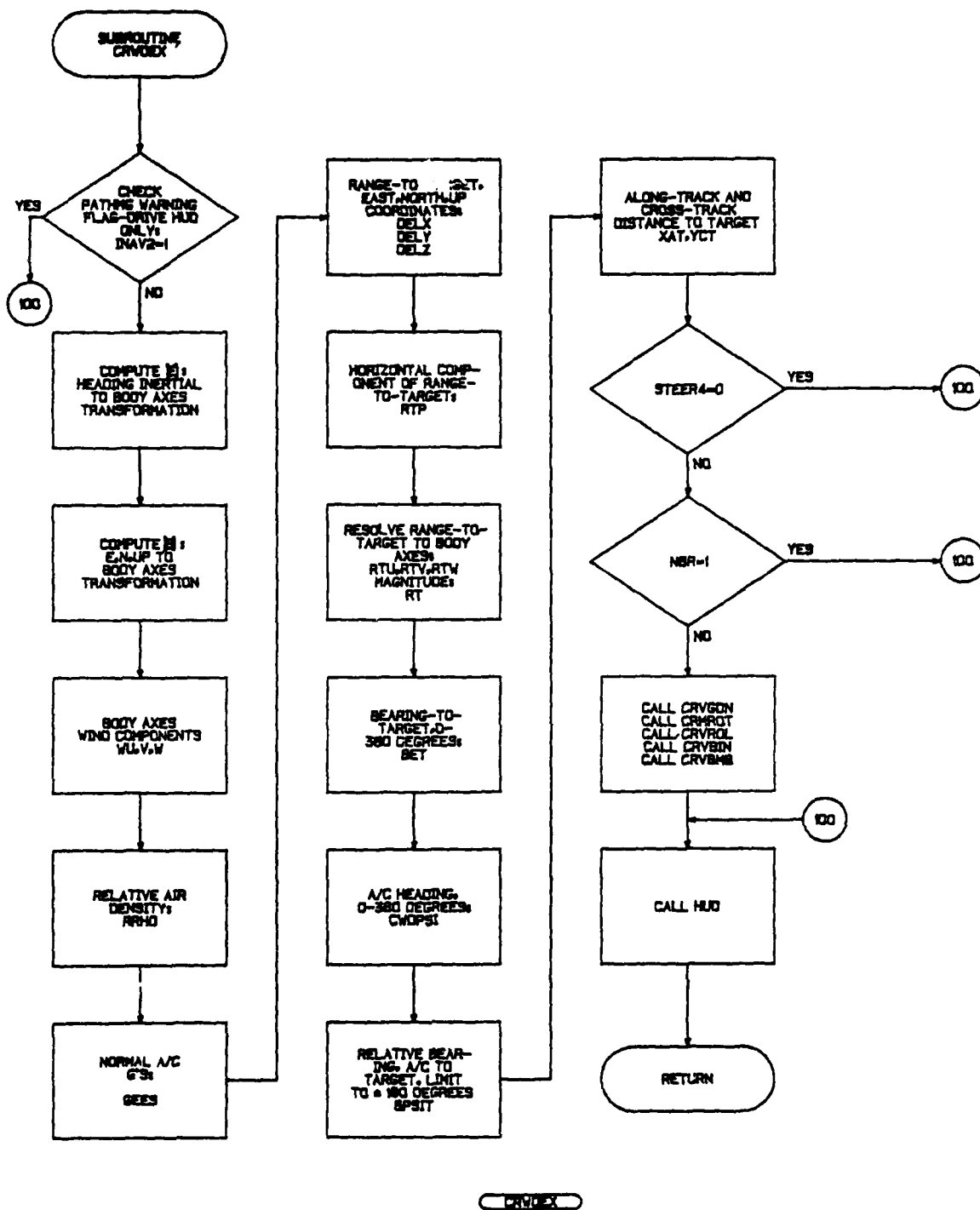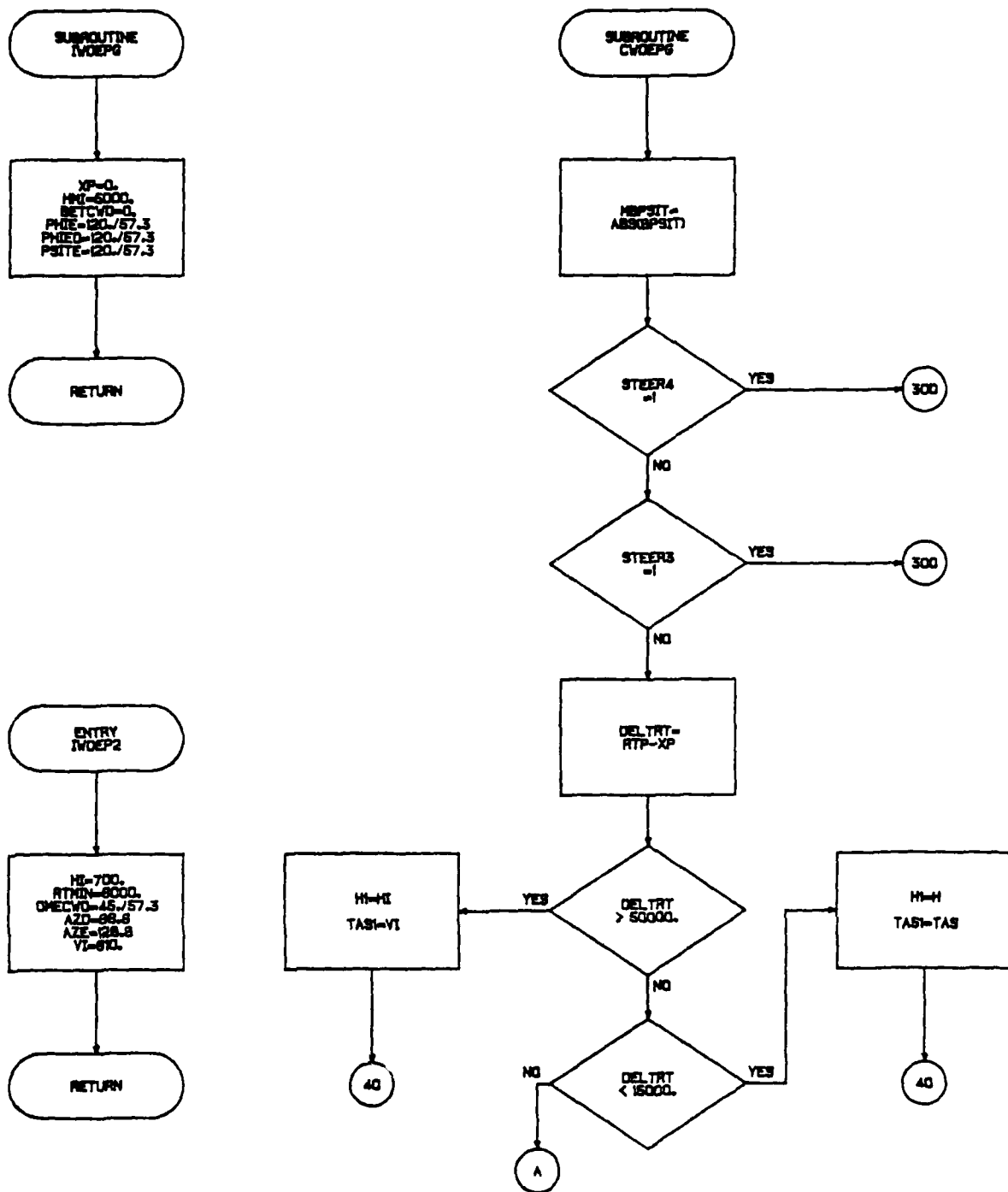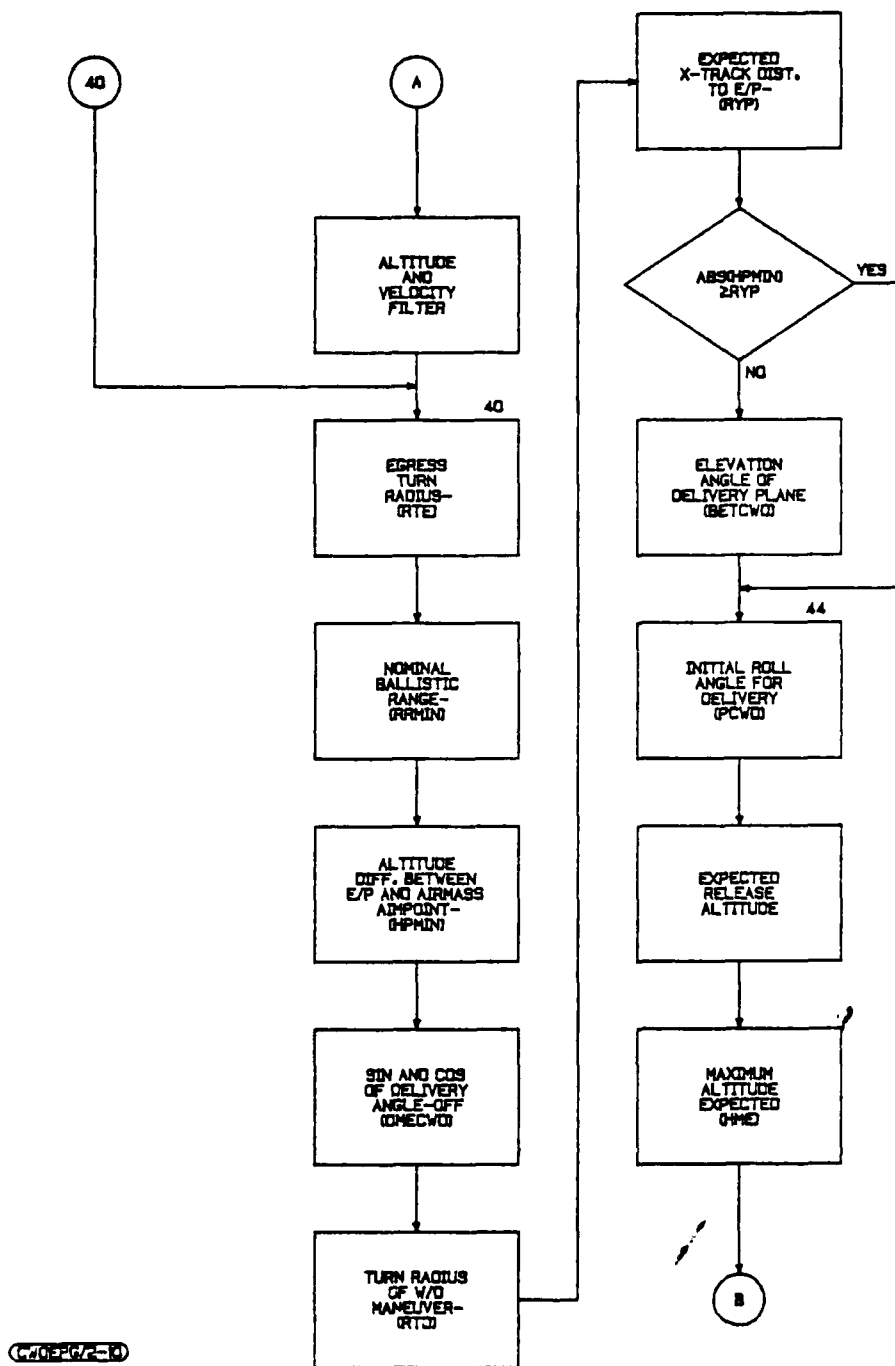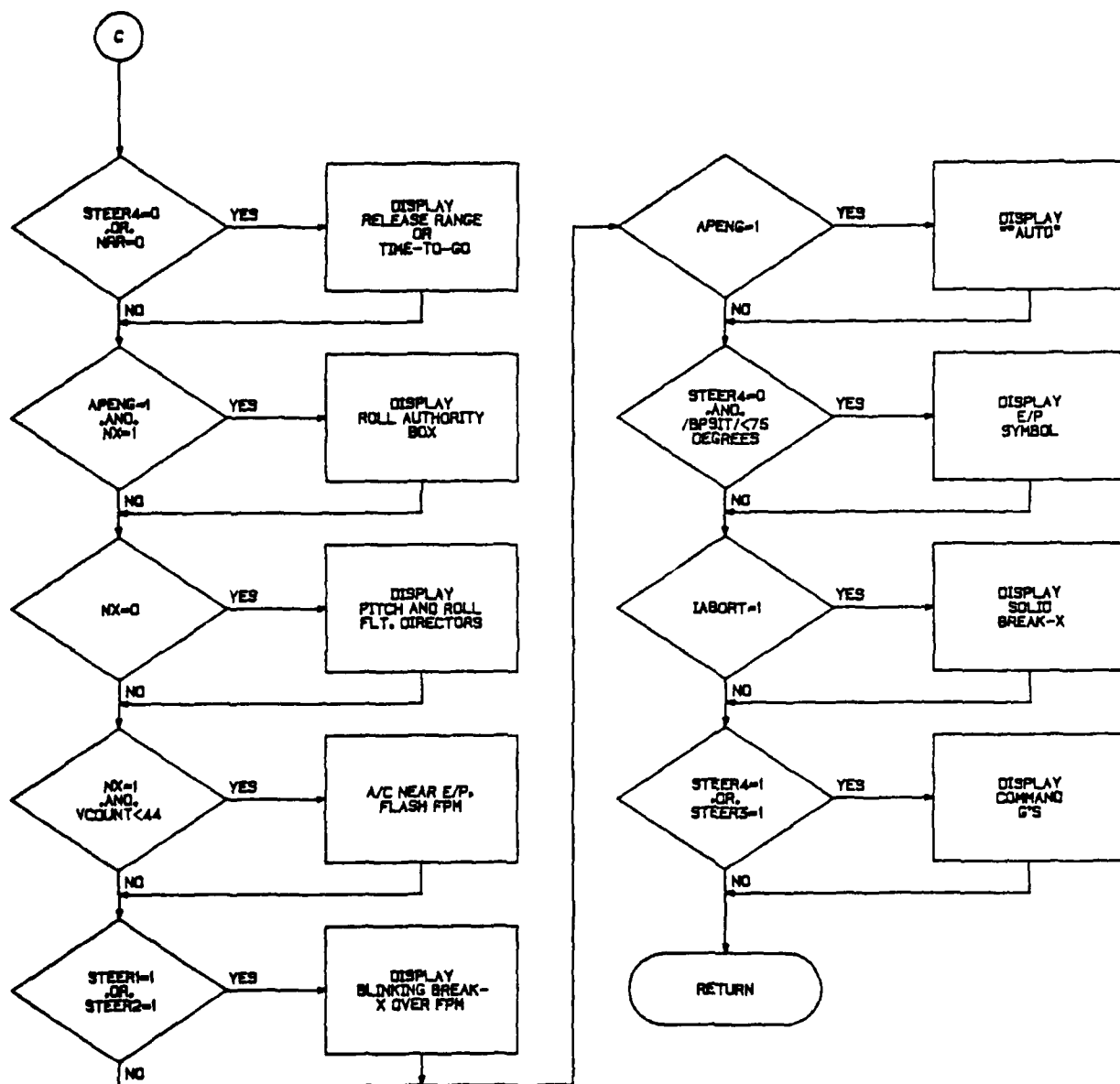Figure A-5. IFTC/Firefly II Integration Flow Charts (21 of 21)

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APPENDIX B

PILOT QUESTIONNAIRES

PRE-FLIGHT QUESTIONNAIRE

A. GENERAL

Name _____

Duty Phone _____ Duty Station _____

Current Responsibilities _____

_____

_____

Current and prior flight duty _____

_____

_____

General Education _____

_____

Any special training _____

_____

B. SPECIFIC EXPERIENCE

1. Have you flown aircraft equipped with a flight director system (i.e., computed steering commands)?   YES   NO   (Circle one)

   If so, which aircraft (and hours)? _____

   _____

   Comments (What did you like/dislike? What is your evaluation of overall usefulness? etc.)

   _____

   _____

   _____

   _____

   _____

2. Have you flown aircraft equipped with a map display?   YES   NO

    Aircraft (and hours) _____

    Comments (likes, dislikes, usefulness, etc.) _____

    _____

    _____

    _____

    _____

3. Have you flown aircraft equipped with an electronic Horizontal Situation
    Display (HSD)?   YES   NO

    Aircraft (and hours) _____

    Comments (likes, dislikes, usefulness, etc.) _____

    _____

    _____

    _____

    _____

4. Have you flown aircraft equipped with a head-up display (HUD)?   YES   NO

    Aircraft (and hours) _____

    Comments (likes, dislikes, usefulness, etc.) _____

    _____

    _____

    _____

    _____

5. Have you flown aircraft equipped with area navigation system?   YES   NO

    Aircraft (and hours) _____

    Comments (likes, dislikes, usefulness, etc.) _____

    _____

    _____

    _____

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6. Have you flown aircraft equipped with a digital computer based weapon delivery system?   YES   NO

   Aircraft (and hours) _____

   Comments (likes, dislikes, usefulness, etc.) _____

   _____

   _____

   _____

C. MISSION PLANNING

1. If you were assigned a low level, ground attack interdiction mission, briefly discuss the following points.

   What information would be essentially already developed for you?

   _____

   _____

   _____

   What tasks/info would you be responsible for?

   _____

   _____

   _____

   What is most important aspect of your preparation?

   _____

   _____

   _____

   What is most painful, time consuming, etc. aspect?

   _____

   _____

   _____

   What would be an average mission preparation time (before flight briefing)?

   _____

2. For a digital navigation-weapon delivery aircraft, have you ever had to load the aircraft with the mission's digital nav data through the cockpit keyboard?

                                                            YES   NO

   How much time was involved? _____

   What difficulty/problems were presented? _____

   _____

   _____

3. If you had a way to transfer the ready room prepared digital nav data to the aircraft en masse without keyboard entry, consider the following potential advantages. Rank advantages; comment if desired.

        a. Shorter preparation/briefing time

        b. Shorter aircraft pre-flight time

        c. Complete accuracy in data transfer

        d. More nav/tactical data practical (more waypoints, alternates, etc.)

        e. Other _____

   ( ) (most important) _____

   _____

   ( ) _____

   _____

   ( ) _____

   _____

   ( ) _____

   _____

   ( ) _____

   _____

4. What potential disadvantages and problems would concern you?

   _____

   _____

D. TIME COORDINATED MISSIONS

1. Time of arrival (TOA) is more important (critical) to some missions than to others. What TOA error would you consider permissible for time-on-target (or as indicated) for the following? (+, early; -, late; mins:secs)

a. Rendezvous for join-up _____

b. Rendezvous for air refueling _____

c. Crossing FEBA _____

d. Air-to-ground close air support _____

e. Air-to-ground multi-plane interdiction _____

f. Air-to-ground long range strike _____

g. Combat air patrol _____

2. What is the most critical mission for TOA that you are familiar with?

a. Mission _____

b. Mission phase _____

c. Mission event _____

d. List some consequences of being early _____

    _____

e. List some consequences of being late _____

    _____

E. CREW WORKLOAD

1. Can a one-man crew handle the workload associated with piloting a weapon delivery aircraft in a hostile tactical environment on a low level interdiction mission?

   a. During VFR?   YES   NO

      If not, why? _____

      _____

   b. During night/all weather?   YES   NO

      If not, why? _____

      _____

2. While progressing to a waypoint or target, you have had to make a significant nav deviation from your flight plan. Now, wanting to resume your mission, which involves a coordinated attack, where time-on-target is important, what are your concerns and problems?

_____

_____

_____

_____

POST-FLIGHT QUESTIONNAIRE

You have just flown a simulation of a high performance aircraft performing air-to-ground weapon delivery in a hostile environment. Your simulator aircraft was equipped with an advanced four-dimensional navigation and trajectory generation system, a Data Transfer Module allowing you to quickly transfer mission planning data to the aircraft, and with an electronic/projection situation display.

We'd like to sample your reactions to the simulation and to the system and we'd like to know how you think we can improve both the simulation and the system. We may not have enough blanks for your answers, so feel free to write on the back of these forms to expand any answers.

Name: _____

Date: _____

SECTIONS

A. General Reaction
B. Trajectory Generator/TOA Control
C. DTM Contribution
D. DTM System Enhancement
E. Map-HSD Display
F. Vertical Situation Display
G. Weapon Delivery Control
H. General Observations

A. GENERAL REACTION

1. Do you feel the scenario presented was realistic; i.e., as projected by operational commands?   YES   NO

  a. What major objections/problems to this scenario did you have?

  _____

  _____

  _____

  b. What general scenario suggestions could you make?

  _____

  _____

  _____

2. In this mission, what measures of piloting performance most concerned you? (Rank, 1 = most, etc.)

  TOA ____   Alt. ____   Air Speed ____   Track ____   Other ____

3. Were the concepts of trajectory predictions and TOA prediction explained well enough for you to use easily during the mission?   YES   NO

4. If these mission concepts were introduced into squadron operations, what additional training (training methods and time required) would you recommend?

  _____

  _____

  _____

B. TRAJECTORY GENERATOR/TOA CONTROL

1. Three-dimensional trajectory generation plus TOA predictions provide the pilot with speed control advisories and allows flight control coupling to generated trajectories. This system has the following potential advantages. Rank each in relative importance; comment as desired.

  More accurate TOA/TOT ( ) _____

  _____

  _____

Better following of planned vertical profile ( ) _____

_____

_____

More accurate ground track control (e.g., during turns) through desired flight

corridors ( ) _____

_____

Recovery of time coordinated mission tasks after unplanned maneuvering inter-

ruptions ( ) _____

_____

Other/general _____

_____

2. What other operational mission tasks could benefit from trajectory-TOA

    predictions? _____

    _____

    _____

3. In a mission such as you just flew, if flown in an actual aircraft there would
    be other tasks such as communication, inter-plane coordination, sensor manage-
    ment, visual bogey search, and so forth. As a pilot in a one-man crew air-
    craft, evaluate the tactical environment workload in such a situation and
    comment on probability of mission success;

    a. In an aircraft with trajectory-TOA prediction and graphic HSD presentation.

        _____

        _____

        _____

    b. In an aircraft with digital nav-weapon control and keyboard control of

        waypoint/target destinations _____

        _____

        _____

c. What would be the major piloting differences between the two aircraft and the effect upon performance?

_____ _____

_____

_____

_____

C. DTM CONTRIBUTION

1. The DTM system provides terminal storage of various detailed data sets, capability to accept new data insertions and to assemble a flight mission planning data set. This data can be transferred to the aircraft, and in-flight mission aircraft data can be stored for post-flight return to the ready room terminal. This system can affect the following mission phases. Show your estimate of DTM advantages/disadvantages by (++, +, 0, -, --); comment as desired.

a. Mission planning: time saved (   ), convenience (   ), data accuracy (   )

_____

_____

b. Mission briefing: time saved (   ), convenience (   ), data accuracy (   )

_____ _____

_____

c. Aircraft preflight: time saved (   ), convenience (   ), data accuracy (   )

_____

_____

d. Inflight mission: time saved (   ), convenience (   ), data accuracy (   )

_____

_____

e. A/C post-flight: time saved (   ), convenience (   ), data accuracy (   )

_____

_____

f. Mission debrief: time saved (   ), convenience (   ), data accuracy (   )

_____

_____

g. Mission reconstruction - analysis:

   time saved (   ), convenience (   ), data accuracy (   )

   _____

   _____

2. What particular effects of using the DTM system do you foresee on the following:

   a. Mission reaction time _____

   _____

   b. Mission performance _____

   _____

   c. Overall command-control effectiveness _____

   _____

3. What problems and inconveniences did you observe or foresee in using the system?

   _____

   _____

   _____

4. As a pilot, would you trust the creation of a flight plan data set to
   someone else?   YES   NO

5. Was the flight plan data printout acceptable?   YES   NO

6. How would you improve the data printout? _____

   _____

   _____

   Would the IFTC system be acceptable without the DTM system, thus requiring
   manual keyboard insertion in the cockpit of all data?   YES   NO

   comment _____

   _____

8. In actual squadron operation, do you expect the pilots would want to enter any actual data through the terminal keyboard?   YES   NO

   If so, why and how much? _____

   _____ _____

9. What procedures, if any, do you foresee the pilot using to check the assembled flight data set accuracy:

   a. While assembling data on the terminal? _____

   _____

   _____

   b. After the DTM is loaded and the data listing printout is available?

   _____

   _____

10. What was the utility of presenting the terminal data in the same format as the

    cockpit displays? _____

    _____

    _____

11. Assuming some more hands-on proficiency was gained in using the DTM terminal, what level-of-effort is required in creating/modifying a flight mission data load?

    _____

    _____

12. Were the self-help CRT terminal instructions worthwhile?   YES   NO

    Comment _____

    _____

13. What DTM system training aspects could be improved? _____

    _____

    _____

D. DTM SYSTEM ENHANCEMENT

1. An x-y digitizer board with a movable cross-hair lens is planned for attach-
   ment to the DTM system terminal. A planning map could be taped to the board
   and nav point lat-longs could be acquired automatically without manual
   measurements and keyboard entry. Do you see this addition as a worthwhile
   system enhancement to simplify the work effort?   YES   NO

   Comment _____

   _____

   _____

2. A second data acquisition aid would be a graphic CRT display that shows a
   map of previously entered and stored nav points. Selection of nav points
   for inclusion in a particular flight data load could then be done with a
   light pen, eliminating the numerical data checking and entry. In addition,
   many keyboard entered instructions could be replaced by using the light
   pen against a menu-list display of permissible instructions at each step.
   Do you see this addition as a worthwhile system enhancement to simplify
   the work effort?   YES   NO

   Comment _____

   _____

   _____

3. In conjunction with computer loading of the data transfer device in the
   ready room and printing a numerical data listing, assume that the computer
   would also generate a "stick map" printout consisting of (1) a background
   of minimal map features and grid lines, (2) all the mission nav point
   positions, as shown by their assigned labels, and (3) an intended flight
   path line. How useful would this graphical printout be for the following
   purposes?

   a. For checking accuracy of mission planning nav data points?

   _____

   _____

   b. For inflight plane/crew coordination reference?

   _____

   _____

c. For making inflight mission management decisions?

_____

_____

c. For (other) _____

_____

4. The DTM terminal computer and graphical printer also could be used for various mission planning and briefing functions. From your squadron experience, comment on the potential utility of the following.

   a. A trajectory generator, TOA predictor such as you flew in the simulator.

   _____

   _____

   b. The addition of fuel usage predictions to the above trajectory generator.

   _____

   _____

   c. Graphical printouts of remotely generated weather maps.

   _____

   _____

   d. Graphical printouts of remotely generated battlefield situation maps.

   _____

   _____   _____

   e. Numerical printouts of other briefing data such as comm plans, etc.

   _____

   _____

   f. Other suggestions _____

   _____

5. Beyond enhancements discussed above, how could the DTM system be improved or extended in usefulness?

   _____

   _____

E. MAP-HSD DISPLAY

1. Was the projected map image easy to view?   YES   NO
    Comment on the following:

    Sharpness _____   _____

    Brightness _____   _____

    Brightness control range _____

    Head position constraints _____

    General _____

2. Was the CRT generated HSD easy to view?   YES   NO
    Comment on the following:

    Sharpness _____   _____

    Brightness _____   _____

    Brightness control range _____

    Balance of CRT and map _____

    General _____

3. What was the most useful map scale (72, 36 or 18 miles top-to-bottom)?_____

4. What other scales would be useful; and during what mission phase?

    _____

    _____

5. What are your general reactions to the projected map-HSD display?

    a. _____

    b. _____

    c. _____

    d. _____

6. What is the utility of the capture profile feature? _____

    _____

7. Is there sufficient need for a north-up display mode? If so, when would you use it? _____

_____

8. Was the HSD symbology update rate adequate?   YES   NO

9. Did the symbols for the threat envelopes and hostile aircraft stand out adequately?   YES   NO

10. In the visual weapon delivery phase, which is primarily a head-up mode of piloting,

    a. What utility, if any, might the HSD furnish? _____

    _____

    b. What utility, if any, might the map furnish? _____

    _____

11. Was the size of the map-HSD comfortable for you?   YES   NO

    Comment _____

12. With more training, could you use the map-HSD display easily in actual missions to get the tactical information needed?   YES   NO

    Comment _____

    _____

F. VERTICAL SITUATION DISPLAY

1. What was the utility of the information presented on the VSD?

    _____

    _____

2. In what mission phases was the VSD most useful?

    a. _____

    b. _____

    c. _____

3. Do you have a different preferred display format for VSD?　　YES　　NO

G. WEAPON DELIVERY CONTROL

1. How well explained were the weapon delivery procedures including ingress, delivery, egress? (Circle one)

    Good explanation　　1　　2　　3　　4　　5　　6　　Confusing

2. How well explained was the HUD symbology?

    Good explanation　　1　　2　　3　　4　　5　　6　　Confusing

3. How understandable were the HUD symbols during actual use?

    Very understandable　　1　　2　　3　　4　　5　　6　　Confusing

4. During ingress to the offset point, is AFC coupled pitch and roll steering desirable?

    Necessary　　1　　2　　3　　4　　5　　6　　Unnecessary

5. During the jinking maneuver, were the roll steering and break-off cues visible and understandable?

    Very clear　　1　　2　　3　　4　　5　　6　　Confusing

6. In a hostile environment, when would you stop jinking during the run-in to the target (in time before stores release)?

_____

7. Pilot specifiable parameters for the weapon delivery maneuver were maximum altitude, delivery G's, egress G's, and minimum closest point of approach to the target. Are these a reasonable set of parameters that the pilot would like to set?   YES   NO

   If not, why? _____

   _____

   _____

8. Are there other weapon run parameters which pilots would like to specify?

   _____

   _____

9. Does the concept of offset bombing with delivery while pulling G's in a turn seem viable to you?   YES   NO

   Advantages _____

   _____

   Disadvantages _____

   _____

10. Does the egress maneuver of a partially inverted turn while pulling G's have some merit?   YES   NO

    Very useful   1   2   3   4   5   6   No utility

11. For this maneuver, what level of trust would you give to the flight computer and coupled roll steering control as demonstrated in the simulator?

    Full, use always   1   2   3   4   5   6   Never use

12. For this maneuver, what limit values would be appropriate?

    Bank angle _____, G's _____, Nose down attitude _____

G. __GENERAL OBSERVATIONS__

1. In general, what maneuvers/mission phases need to be coupled to the autopilot?

   a. _____

   b. _____

   c. _____

   d. _____

2. What new features that were demonstrated did you like?

   a. _____

   b. _____

   c. _____

   d. _____

3. What improvements/changes would you suggest?

   a. _____

   b. _____

   c. _____

   d. _____

4. If you would prefer a rearranged instrument panel, please sketch below.

Thank you. We appreciate greatly the information contained in your reactions and suggestions.

APPENDIX C

SIMULATION STRUCTURE DESCRIPTION

AND FLOW CHARTS

C.1 IFTC EXECUTIVE PROGRAM

The IFTC simulation is structured with four major blocks of related algorithms. Each block is referred to as a "task" and may consist of several "branches". The tasks (I-IV) are shown in Figures C-1 to C-4, respectively, with a typical "branch" indicated in Figure C-1. The major functions performed by each task are as follows:

Task	Function
I (H4D)	Initialization; Path Management; Trajectory Generation; Time-Speed Scheduling; Fuel Remaining.
II (FDRT)	Cockpit Keys Management; Data Link Simulation and Processing; Cockpit Status Display Paging Management.
III (H4DRIC)	Control/Displays Management; Cockpit Annunciators; Map Processing and Data Transmittal Management.
IV (ACWDGD)	Weapon Delivery Functions; Guidance; Aircraft Model; Real-Time Scheduling of other tasks.

C.2 REAL-TIME INTERRUPT ROUTINE

The simulation was structured with one interrupt-driven task, Task IV, which, in turn, schedules the other tasks in an orderly fashion. Execution of Task IV begins when the 50-ms interrupt occurs. If ICNTR is equal to 1, the event flag is set to enable the execution of Task II. Execution of Task II will not begin immediately (because of its lower priority than Task IV), but when Task IV completes execution for that interrupt cycle.

Task II executes according to the flow described in Figure C-5. Note especially that the execution flags for Task I and Task III are enabled by Task II.

The following paragraphs describe the sequence of events which occur following the detection of the data link input.

Subroutine H4DRT2 (Figure C-6) checks for a data link input. Upon detection of this input, the associated code is determined and the data link cockpit annunciator light is illuminated. If the data

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link input requires a new trajectory to be computed, the necessary flags are set, allowing Task I to compute the new trajectory. If, during the execution of Task I, II, or III, a 50-ms interrupt occurs, computation is suspended and control is transferred to Task IV processing. Completion of Task IV again results in the enabling of the other tasks. (See Timing Diagram, Figure C-7.)

When the trajectory generator has completed the computation of the new trajectory, a flag is passed to subroutine OPERA in Task III which, in turn, controls the transfer of the new trajectory data to MAPGEN and STAGEN. MAPGEN sets the appropriate flags and passes the new data to the map symbol generator processor. STAGEN controls the flow of data to the A/C status display. Pilot actions resulting in trajectory modifications are processed in much the same fashion.

Figure C-8 shows increased detail of the sequence of events of Task IV, the real-time interrupt-driven routine.
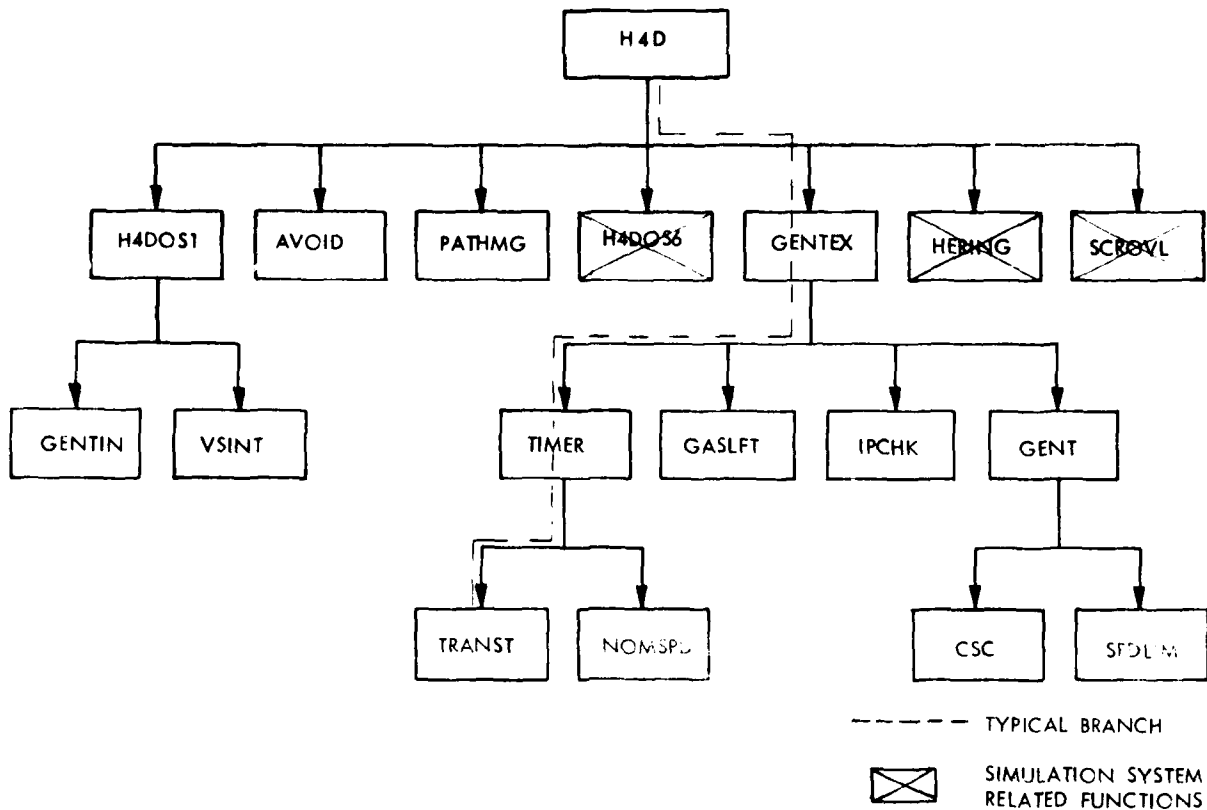
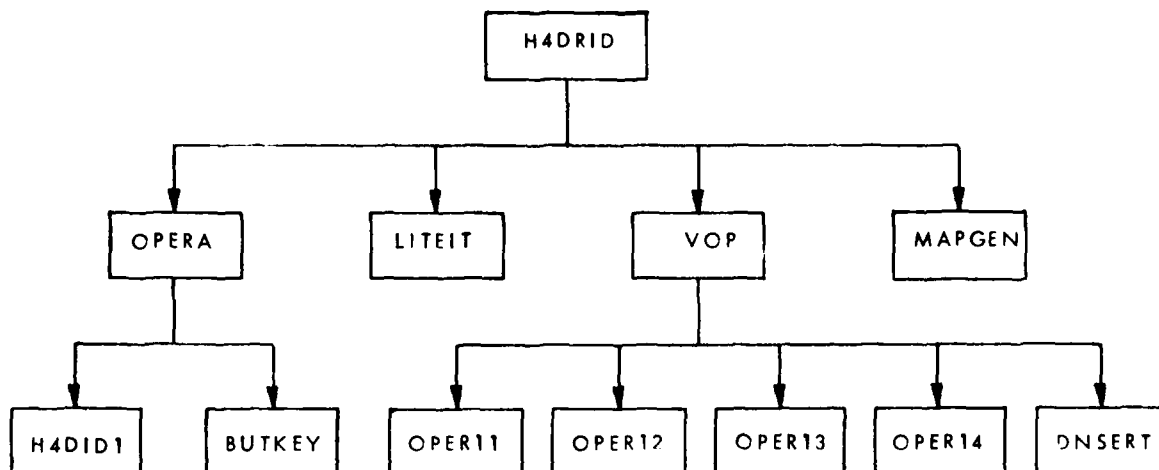Figure C-1. Task I Block Diagram
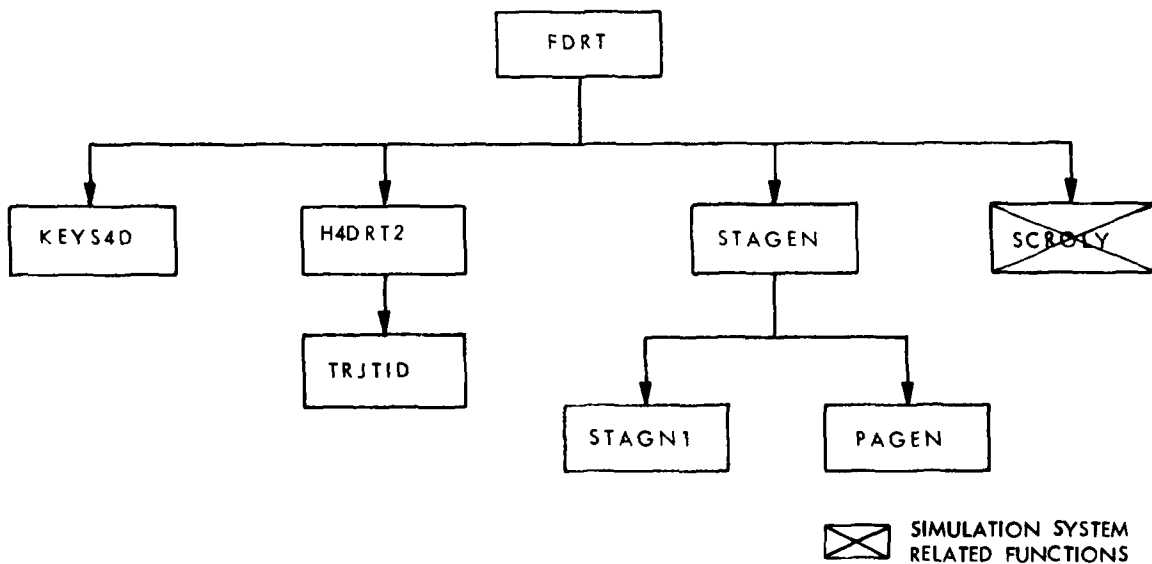
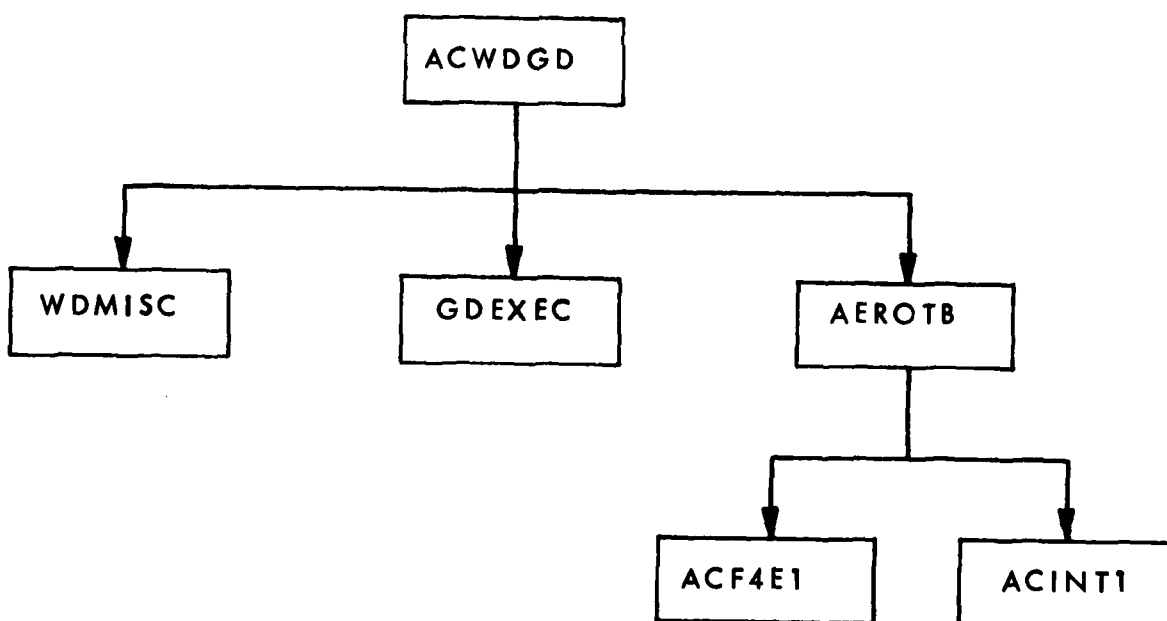Figure C-2. Task II Block Diagram

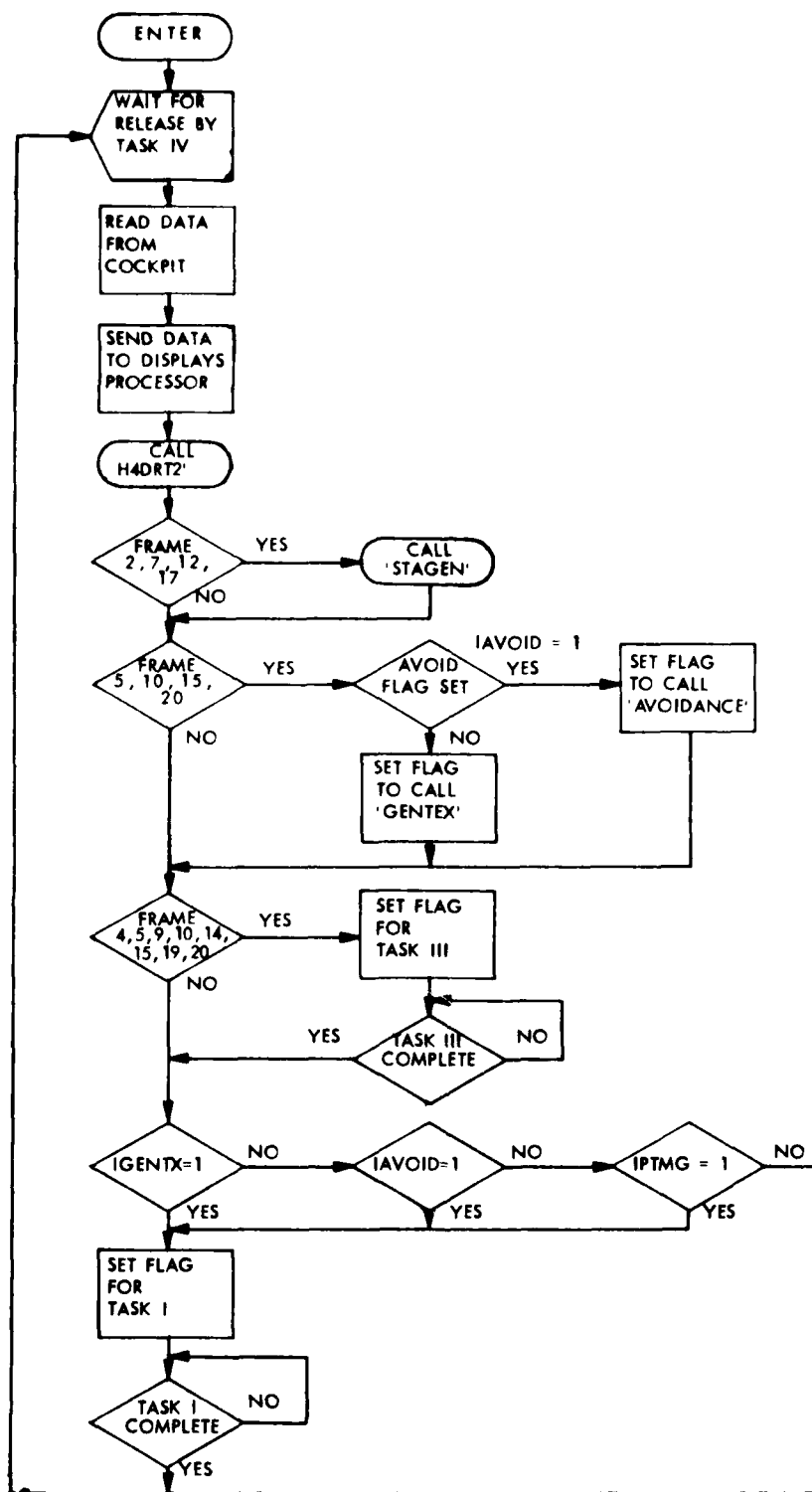Figure C-3.   Task III Block Diagram

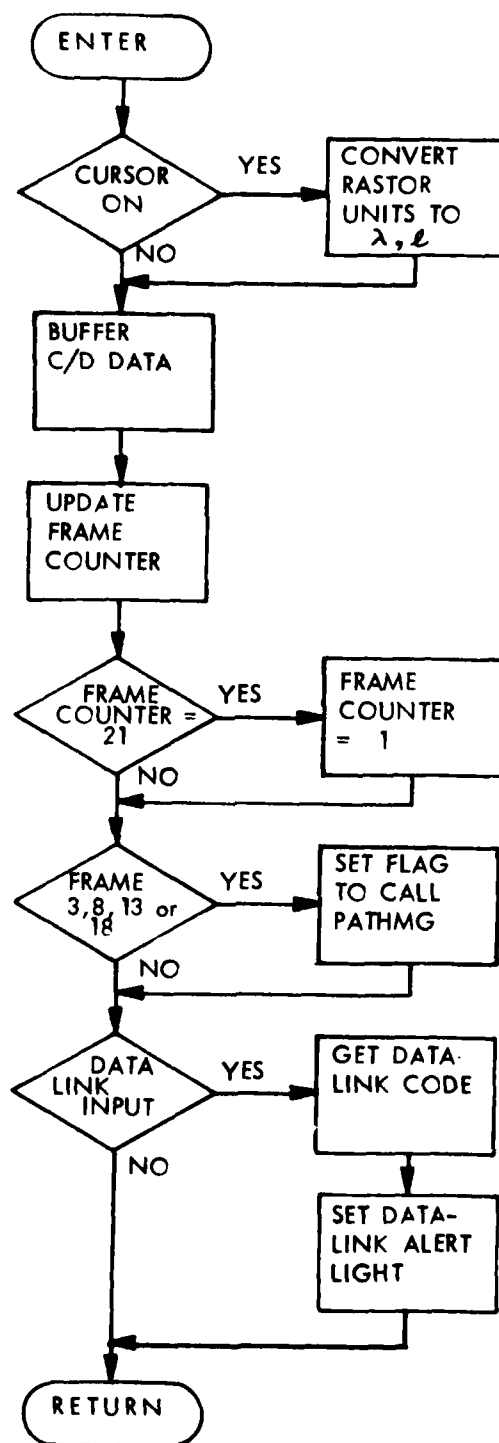Figure C-4.   Task IV Block Diagram

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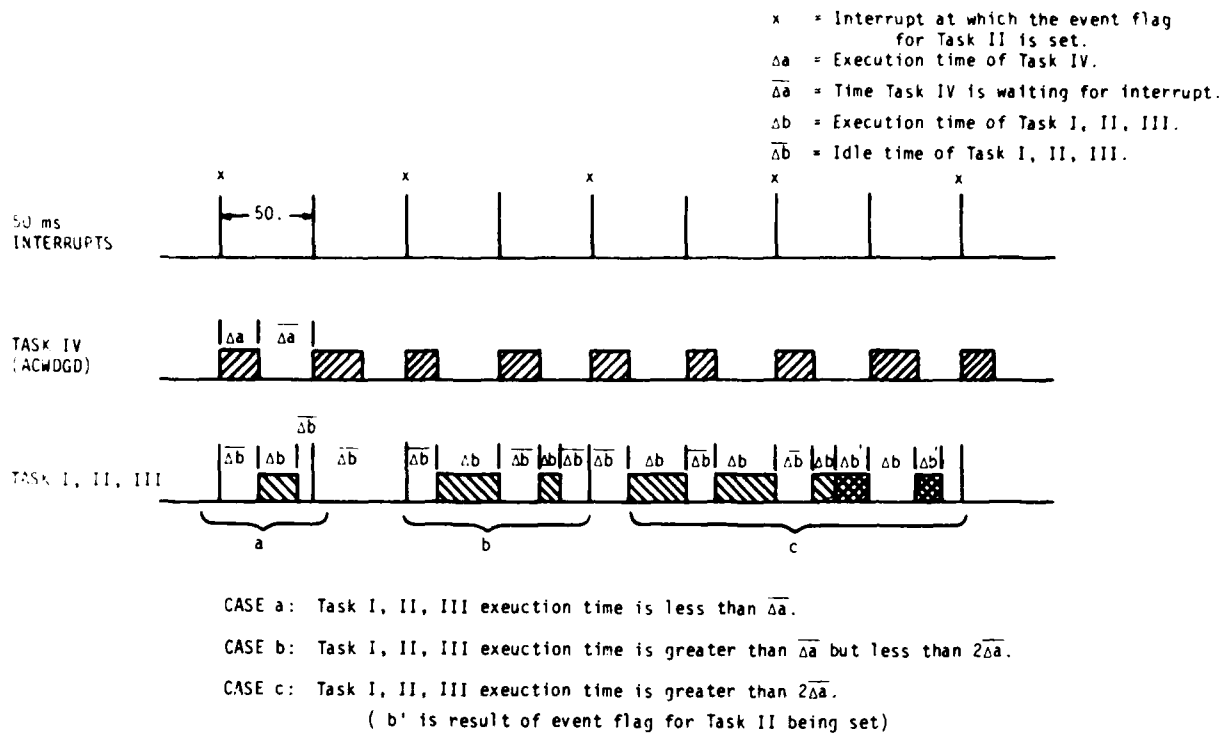Figure C-5. FDRT Flow Chart

Figure C-6. H4DRT2 Flow Chart
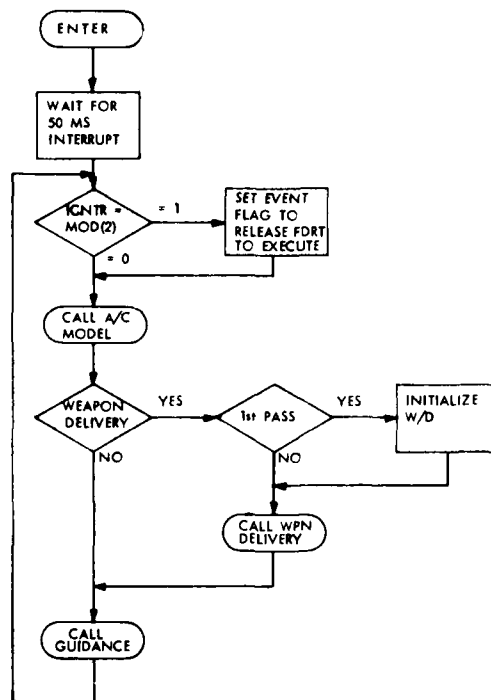
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Figure C-7.   IFTC Executive Timing Diagram

Figure C-8.   50-MS Interrupt Routine Flow Chart

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